CRWR Online Report 99-4

Geospatial Data in Water Availability Modeling

by

Bradley Taylor Hudgens, MSE

Graduate Research Assistant

and

David R. Maidment, PhD.

Principal Investigator

December 1999

CENTER FOR RESEARCH IN WATER RESOURCES

Bureau of Engineering Research • The University of Texas at Austin
J.J. Pickle Research Campus • Austin, TX 78712-4497

This document is available online via World Wide Web at
http://www.ce.utexas.edu/centers/crwr/reports/online.html

Small erections may be finished by their first architects; grand ones, true ones, ever leave the copestone to posterity. God keep me from ever completing anything. This whole book is but a draught – nay, but the draught of a draught. Oh, Time, Strength, Cash, and Patience!

Herman Melville, *Moby Dick*

One was my belief that the water problem, crucial to all Texas, can be solved only when the people of Texas become conscious of their imperative needs and only if they become informed and aroused enough to act.

Betty Dobkins, *The Spanish Element in Texas Water Law*

You will finally solve a difficult problem that will mean much to you.

anonymous fortune cookie, August 1999

Acknowledgements

The study presented in this thesis is funded by the Texas Natural Resource Conservation Commission. Their support is gratefully acknowledged. The author would also like to thank Dr. David Maidment and Dr. Francisco Olivera for lending their technical expertise in all aspects of the study. Finally, the author would like to thank the other members of the Center for Research in Water Resources for their generous support.

December 3, 1999

Abstract

Geospatial Data in Water Availability Modeling

Bradley Taylor Hudgens, M.S.E.

The University of Texas at Austin, 1999

Supervisor: David R. Maidment

A method is presented for determining flow distribution parameters of drainage area, curve number, and mean annual precipitation from geospatial data sets. The parameters are used to distribute naturalized streamflows from gaged sites to ungaged sites in a water availability model. The method is illustrated by application to the Sulphur River basin in Northeast Texas. Two scales of digital elevation data, 1:250,000 and 1:24,000, are used to automatically delineate watersheds for selected points in the basin. A digital stream network is built by adding manually digitized tributaries from 1:24,000 scale topographic maps to an existing 1:100,000 scale stream coverage. The stream network is used to modify the digital elevation data to better reflect mapped hydrography. Watersheds defined by the 1:24,000 scale elevation data are observed to accurately reflect the land surface shown on a 1:24,000 scale topographic map. Curve number and precipitation parameters for these watersheds are extracted from existing geospatial data sources.

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

1.1 Background

1.1.1 The Water Availability Modeling Project

Water is a critical resource in the state of Texas. A worst case study prepared in 1984 by the Texas Water Development Board predicted a demand for the state in the year 2000 of 25.4 million acre-feet against an available supply, including both surface and ground waters, of 25.1 million acre-feet (TWDB, 1984). Of course, we have yet to meet this worst case scenario. The Texas Society of Professional Engineers, as far back as 1954, calculated that the average annual runoff in the state amounts to 53 million acre-feet (Dobkins, 1959). This supply figure does not include groundwater. So, in an average year, it appears that there would be plenty of water available to satisfy the demands of the state, even allowing for growth in future years.

But providing an adequate water supply throughout the state is not as simple as just balancing total available water against demands. Not all runoff can be developed into water supply; in-stream requirements, for example, must still be met. Unrestricted use of groundwater will eventually deplete the resource and draw down the base flows of surface waters. Most importantly, in Texas the distribution of water is highly variable over both space and time. Average annual precipitation varies from 0 to 10 inches in the arid West, to over 50 inches in the East. The annual runoff for all streams in the state, while averaging 53 million acre-feet, has historically varied over a range of 20 to 90 million acre-feet (Dobkins, 1959).

To reconcile ever-increasing demands with an unpredictable supply, the surface waters of the state are managed under the Texas Water Code through a system of water rights. The state grants rights to the flow and use of surface waters through water permits. The Texas Natural Resource Conservation Commission (TNRCC) has the authority to manage water rights in the state. Groundwater is legally treated as the property of the landowner, and is not regulated in this manner. The present Texas Water Code is an administrative system of water law. There are three general doctrines recognized in water law: riparian, prior appropriation, and administrative. Dobkins explains these systems:

> The riparian system says that the man who owns the bank of the stream (*ripa* in Latin) is entitled to the use of the waters of the stream as an appurtenance to his land. The system of prior appropriation holds that the man who first put the water to a beneficial use, whether he owns the land along the stream or wherever he may use the water, acquires a right to the continued use of the water. "First in time is first in right." The administrative system provides for the issuing of permits for the use of water by some state agency. The riparian and appropriative systems have been the two great rivals; the administrative system has developed out of the two, especially the system of appropriation, in response to the changing needs of man and the governing uses of water (Dobkins, 1959).

These approaches share a basic principle: that the running water in a stream is not attached to a property right; that is, the actual water belongs to the state, to be held in trust for the people. The state then grants water rights to the flow and use of the stream through one of the above systems. Water taken under a water right becomes real property, in the legal sense, as long as it is held and used. Texas has evolved through each of these systems, retaining some of each doctrine as it went.

The Republic of Texas formally adopted a riparian doctrine in 1840. By 1889, however, the State of Texas had begun the transition to a prior appropriations doctrine under the Irrigation Acts of 1889 and 1895. Even while the state completely transitioned to an appropriation system with the Burges-Glasscock Act of 1913, riparian rights from previous land grants, including grants of Spanish and Mexican origin, continued to be held legal. The 1913 act also created the Board of Water Engineers, which required a permit to be issued for any appropriation of water. The inherent problems of this dual system were exposed in the 1950s when the state experienced a severe drought. During this decade there was much confusion and contention over the diversion amounts claimed and authorized. Suddenly, large claims were made on riparian rights that had never been exercised before, and previously excessive amounts permitted in some appropriation rights now caused junior rights to be shorted.

The present administrative system of water law in Texas arose out of this conflict. The Water Rights Adjudication Act, passed in 1967, phased out riparian rights, requiring them to show records of actual beneficial use over the previous five years. It empowered the Texas Water Commission (a predecessor to the TNRCC) to adjudicate among all claims on a given stream segment. This process has now been completed for most of the state, but is still underway along the upper Rio Grande. There are now two types of water rights in Texas: permits, issued by the TNRCC, and certificates of adjudication, rights derived from any source that have been adjudicated out of the 1967 act. Presently, there are over 6,200 surface water rights in the state (Town, 1999). The text of a water permit, permit number 5,000 issued by the state to the city of Mart in 1986, is reproduced here as a reference (TNRCC, 1999).

PERMIT TO
APPROPRIATE STATE WATER

APPLICATION NO. 5000 PERMIT NO. 5000 TYPE: §11.121 & §11.028

Permittee: City of Mart Address: P.O. Box 360
Mart, Texas 76664

Filed: September 3, 1985

Granted: January 21, 1986 County: McLennan

Watercourse: Unnamed tributary of Tradinghouse Creek, tributary of Tehuacana Creek, tributary of Brazos River

Watershed: Brazos River Basin

WHEREAS, the Texas Water Commission finds that jurisdiction of this application is established and due notice thereof has been given in accordance with the Texas Water Code and the Rules of the Commission;

NOW, THEREFORE, this permit to appropriate and use State water is issued to City of Mart, subject to the following terms and conditions:

1. IMPOUNDMENT

Permittee is authorized to maintain an existing dam and reservoir (New Lake Mart) on an unnamed tributary of Tradinghouse Creek and impound therein not to exceed 1640 acre-feet of water. The dam is in the Tomas De La Vega Survey, Abstract No. 43, McLennan County about 12 miles east of Waco, Texas and Station 0+00 on the centerline of the dam is S 78° W, 7055 feet from the SE corner of the survey.

2. USE

Permittee is authorized to use the impounded water for recreational purposes and to divert and use not to exceed 500 acre-feet of water per annum from the reservoir for municipal purposes.

3. DIVERSION

Permittee is authorized to divert water from a point on the reservoir S 78°15' W, 7025 feet from the aforesaid survey corner at a maximum rate of 1.6 cfs (700 gpm).

4. SPECIAL CONDITIONS

(a) The diversion, impoundment and use herein authorized from an unnamed tributary of Tradinghouse Creek, Brazos River Basin, for municipal purposes shall have a priority date of May 17, 1931 as to all authorized appropriations in the Brazos River Basin for purposes other than domestic or municipal. As to other authorized appropriations in the Brazos River Basin for domestic and municipal use, the diversion, impoundment and use herein authorized shall have a priority date of September 3, 1985, being the date this application was filed with the Texas Water Commission.

(b) Whenever the Commission finds that permittee is impounding any water to which holders of superior and senior water rights are entitled, the permittee shall release water ordered by the Commission.

This permit is issued subject to all superior and senior water rights in the Brazos River Basin.

Permittee agrees to be bound by the terms, conditions and provisions contained herein and such agreement is a condition precedent to the granting of this permit.

All other matters requested in the application which are not specifically granted by this permit are denied.

This permit is issued subject to the Rules of the Texas Water Commission and to the right of continual supervision of State water resources exercised by the Commission.

	TEXAS WATER COMMISSION
	/s/ Paul Hopkins
DATE ISSUED:	Paul Hopkins, Chairman
January 31, 1986	
	/s/ Ralph Roming
ATTEST:	Ralph Roming, Commissioner
/s/ Mary Ann Hefner	/s/ John 0. Houchins
Mary Ann Hefner, Chief Clerk	John 0. Houchins, Commissioner

Drought once again struck Texas in 1996 and, once again, ignited disputes over water rights. In August of 1996, TNRCC reported that stream flows throughout the state ranged from 11 to 50 percent of average historical values. (TNRCC, 1999) The Texas legislature recognized the need for improved water management in the state. Texas Senate Bill 1 was passed in 1997, directing, among other things, that TNRCC produce water availability models for 22 of the state's 23 major river basins, the exception being the Rio Grande, which will be modeled separately. These water availability models will serve as decision support systems for water planners in the state and provide useful information to water users.

TNRCC defines water availability models as "computer programs that calculate the amount of water in a river basin using hydrologic principles and actual measurements taken at stream gages" (TNRCC, 1999). Water availability models have been used previously in the state on a limited basis. TNRCC describes the limitations of these earlier models:

> During the 1970s and 1980s, the predecessor agencies of the TNRCC developed water availability models for eight river basins. These models were basin-specific and are now considered obsolete. These older models

simply lack the design capacity to handle all the data inputs and calculations needed for full water resource management in the state of Texas (TNRCC, 1999).

In response to the modeling requirement of Senate Bill 1, TNRCC initiated the Water Availability Modeling (WAM) System project. The proposed WAM system is illustrated in Figure 1.1 :

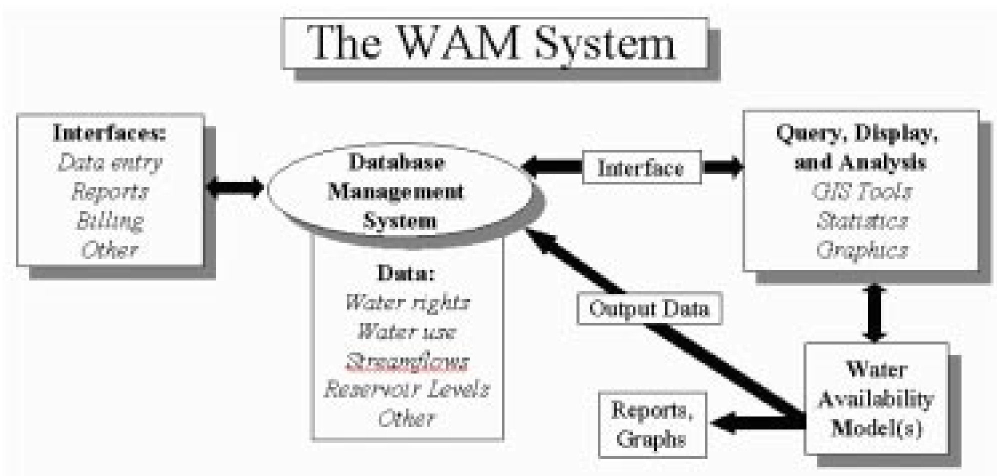


Figure 1.1 : The Water Availability Modeling System (TNRCC, 1999**)**

Several existing water availability models were evaluated by TNRCC, and the Texas A&M Water Rights Analysis Package (WRAP) was selected as the common model to be used in each river basin. As shown in Figure 1.1, Geographic Information Systems (GIS) tools are necessary for the system to link the database management system and the water availability model. The University of Texas at Austin Center for Research in Water Resources' (CRWR) Prepro system was selected to provide this component.

CRWR Prepro was originally developed as a GIS preprocessor to the Hydrologic Engineering Center's (HEC) Hydrologic Modeling System (HMS) watershed model. GIS works with geospatial data, that is, data that has both a geographic spatial location and associated descriptive attributes. CRWR Prepro is built on the Environmental Systems Research Institute's (ESRI) ArcInfo and ArcView GIS software packages. CRWR Prepro reads watershed data from geospatial data sets and prepares a basin file as input to the HMS model. The basic methods of hydrologic processing used in CRWR Prepro may be similarly applied in building input data sets for any watershed model. In this research, CRWR Prepro has been modified to serve the needs of the WAM system.

1.1.2 WRAP Flow Distribution Parameters

TNRCC envisions the water availability modeling process in two phases (TNRCC, 1999). In phase one, monthly naturalized streamflows are developed at all sites which are to be simulated in the model. Naturalized streamflows, also known as unregulated flows, are the flows which would exist in a stream without the effects of man's development. These are calculated by taking measured flows, typically from USGS stream gages, and adding or subtracting terms for water loss, gain, and storage, such as those available from historical records of reservoir storage and water diversions. Naturalized flows are initially calculated for the few points in a river basin that have historical records, such as stream gages. Flows from these locations may then be used to estimate naturalized flows at points with no historical records. This process is called flow distribution. Phase two of the water availability process is the simulation of the basin system to perform water allocations among the water rights (water demands) based on the input sequences of naturalized streamflows (the water supply) for each point.

In the WRAP model, points for which flows are to be input or allocated are called control points. For each control point, the user identifies the next downstream control point. In this way, the model establishes connectivity within the system. In the WAM project, control points for which naturalized flows have initially been calculated are called primary control points, while those to which naturalized flows are distributed are called secondary control points. Figure 1.2 shows the primary and secondary control points that are used in the WRAP model of the Sulphur river basin.

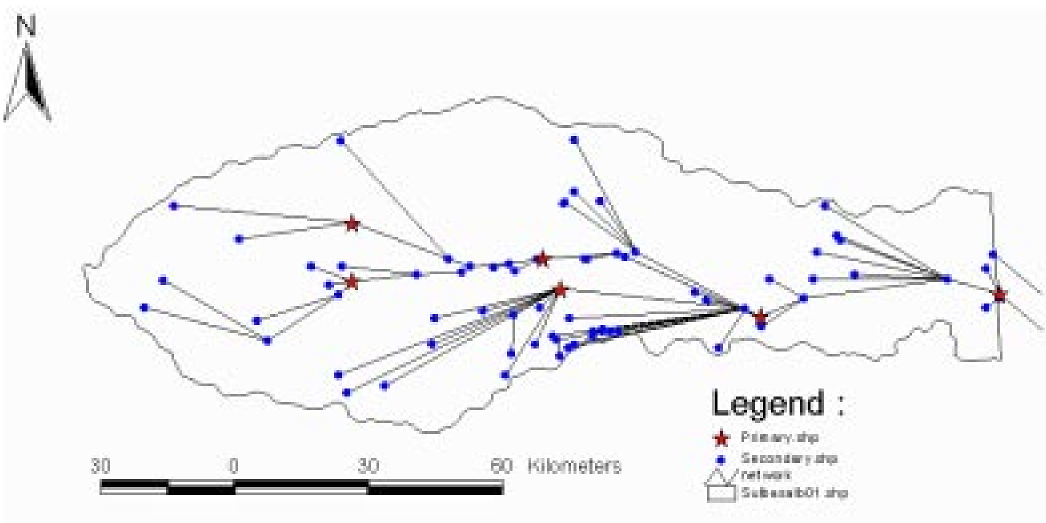


Figure 1.2 : Primary and Secondary Control Points in the Sulphur Basin

The WRAP modeling package is a set of FORTRAN programs : RECORDS, WRAP-SIM, and TABLES. Figure 1.3 shows these program blocks and the input and output files exchanged among them.

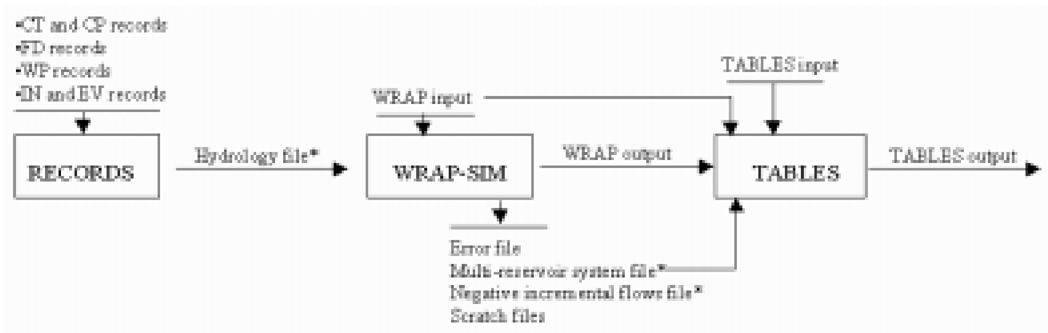


Figure 1.3 : The WRAP Model Components

RECORDS is a preprocessor that is used to distribute flows from primary to secondary control points. WRAP-SIM is the actual water allocation model. TABLES is a postprocessor that organizes the WRAP-SIM output into summary tables. Input is made to, and output taken from, the model as field-formatted text files. The work done in this study prepares the hydrological parameters used in RECORDS to distribute flows. The parameters are input to the model in the WP records file. The contents of this file for one sub-watershed in the Sulphur basin are shown in Table 1.1.

Control Point	Area (sq. mi.)	Curve Number	Precipitation (in./yr.)
A10	541.01	69.6	42.8
A20	1.66	71.5	44.0
A30	12.44	69.9	43.0
A40	504.58	69.4	42.7
A50	106.34	69.9	42.4
A60	223.33	69.7	42.2
A70	1.03	72.8	42.0

Table 1.1 : Example of Records in the WP Input File

There are several methods for performing flow distributions. Dr. Ralph Wurbs of Texas A&M University has made a study of these for the WAM project (Wurbs, 1998). The parameters derived in this study are produced specifically to support the NRCS Curve Number Method Adaptation of flow distribution. This method is based on the NRCS curve number (CN) relationship between rainfall depth, P in inches, and runoff depth, Q in inches, given in Equation 1.1.

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \quad where \quad S = \frac{1{,}000}{CN} - 10 \qquad (1.1)$$

In this formula, S represents the total amount of water that can be abstracted by the watershed. Abstracted water is rainfall that is not transformed into runoff. For example, rainfall may be stored at the surface or infiltrate into the ground. For convenience, S is expressed as a dimensionless curve number, CN, ranging from 0 to 100. The curve number for a watershed is typically derived from a study of the land use and soil composition within the watershed.

The curve number adaptation method of flow distribution works backwards from a known flow to give an average precipitation depth over a watershed. This precipitation depth is then distributed to another watershed, where the flow is determined by Equation 1.1. To account for long-term precipitation differences between two areas, the ratio of mean annual precipitation values for the two watersheds may be used to adjust the value of P that is distributed. This method is described in detail by Wurbs (1998):

Step 1: The flow at the gage, in acre-feet/month is divided by the drainage area A_{gage} and multiplied by a unit conversion factor to convert to an equivalent depth Q_{gage} in inches.

Step 2 : Q_{gage} is input to the curve number equation [Equation 1.1] to obtain P_{gage} in inches. An iterative method is required to solve [Equation 1.1] for P. This approximation is assumed to be applicable to the ungaged watershed as well as the gaged watershed. Base flow is being distributed along with storm runoff, all in the same proportion.

Step 3 : If the long-term mean precipitation varies between the watershed and subwatershed, the precipitation depth may optionally be adjusted by multiplying P_{gage} by the ratio of the long-term mean precipitation depth of the subwatershed to that of the watershed to obtain a $P_{ungaged}$ adjusted in proportion to mean precipitation.

$$adjusted\ P_{ungaged} = P_{gage}\left(\frac{M_{ungaged}}{M_{gage}}\right) \qquad [1.2]$$

where $M_{ungaged}$ and M_{gaged} are the mean precipitation for the ungaged subwatershed and gaged watershed. Otherwise, $P_{ungaged}$ is assumed equal to P_{gage}.

Step 4 : $P_{ungaged}$ is input into [Equation 1.1] to obtain $Q_{ungaged}$ in inches. $Q_{ungaged}$ in inches is multiplied by $A_{ungaged}$ and a unit conversion factor to convert to flow in acre-feet/month.

The magnitude of the drainage area values applied in steps one and four are the dominant factors in determining the amount of flow distributed. In many applications of flow distribution, in fact, flows have been distributed based only on the drainage area ratio, as shown in Equation 1.3.

$$Q_{ungaged} = Q_{gage}\left(\frac{A_{ungaged}}{A_{gaged}}\right) \qquad (1.3)$$

1.2 RESEARCH OBJECTIVES

This research has three objectives:

1. Create a geospatial database for a river basin,
2. Extract the WRAP flow distribution parameters for each control point from the database,
3. Produce reliable digital watershed delineations.

The construction of a geospatial database is the most time-consuming task in this study. While many of the procedures necessary to accomplish this task already existed prior to this research, some modifications have been made to these and new procedures have been developed. Both the ArcInfo and ArcView software packages are used throughout this project. One goal of this project has been to develop most of the necessary procedures in the more user-friendly ArcView environment. ArcInfo is still used primarily in creating the geospatial database, however.

The most important parameter in performing flow distribution is that of drainage area. In this study, drainage areas are calculated from digital elevation data. While the basic method of delineating watersheds from digital elevation data is well-documented, measures of the reliability of this method are not. The only drainage area values available for comparison are those calculated by the USGS for stream gages. For other drainage areas in the project, the actual watershed boundaries must be examined. Digital topographic data, in the form of USGS Digital Raster Graphic (DRG) files, provides a means for comparing watershed boundaries defined from digital elevation data against the mapped terrain. This comparison, however, will always be somewhat subjective, especially in flat areas where contour lines are widely spaced.

This research will be considered a success if the first two goals, establishment of a database and WRAP input parameter processing for a river basin can be accomplished, documented, and reproduced; and if the third goal, producing reliable drainage areas, can be subjectively accepted as accomplished.

1.3 LITERATURE REVIEWED

For each of the research objectives, the available literature has been reviewed to establish the current state of knowledge in these areas.

1.3.1 Building a Geospatial Database

There is ample literature addressing the creation of geospatial databases for use with hydrological models. Research projects by Saunders (1996), Dartiguenave (1998), Quenzer (1998), and Jonsdottir (1999) have all required the development of databases containing several layers of geospatial data. Two key components in these databases are the digital elevation model (DEM) and a digital representation of the mapped stream network.

All of the projects use a DEM as the basic spatial data source in defining the hydrography of the study basin. Studies in coastal areas, such as those by Saunders and Quenzer, have shown that in flat terrain the DEM hydrography may depart to a large extent from that shown by map products. Mapped stream networks can be used to condition a DEM to more accurately reflect the observed channel system. A method has been developed at CRWR to condition a DEM with a vector data set of observed streams (Olivera, 1998). In this methodology, the spatial data set of the mapped stream network is an important component of the database.

Horton (1945) first popularized the notion of a channel network. He introduced a pattern for describing dendritic networks, classifying the smallest unbranched tributaries as first order streams, and assigning subsequent streams a higher order below the junction of two streams of equal order. This concept has since been used frequently in geomorphological and hydrological studies of channel systems and drainage basins. Kirkby (1993) points out that channel networks have both a spatial expression, their planform view, and temporal expression, changing over time with physical and climatological processes.

The spatial expression of channel networks has been defined by several methods. With any method, the most difficult task is to locate the first order tributaries. These are hardest to identify, being the most subject to temporal change. Bauer (1980) recommends four methods of channel location: the blue-line method, the contour-crenulation method, aerial-photograph interpretation, and field-inspection. The blue-line method considers all streams shown as blue lines on a map. Zavoianu (1985) points out two shortcomings to this method. Even a large-scale (1:24,000) map will omit true first-order tributaries, and the streams that are shown will depend on that particular snapshot of time when the aerial photography from which the map is drawn was taken. The contour-crenulation method locates streams from the configuration of topographic lines on contour maps. Bauer (1980) proposes the rule that a first-order tributary can be deduced from two or more consecutive contour angles of no greater than 120 degrees. The method of identifying streams from aerial photographs is similar to the blue-line method and also has the shortcoming of being a snapshot in time. Field-inspection would be the most accurate method of locating streams, but the time and labor cost is prohibitive for any studies but those of very small basins. These methods of defining a stream network are not exclusive, however, rather they can be used to complement one another (Zavoianu, 1985).

Digital stream networks in GIS have most often been defined from digital elevation models. For smaller scale projects, triangulated irregular networks have also been used. In this method, any internal sinks in the elevation data are filled so that continuous overland flow is assumed from the each cell to the basin outlet. Streams are then defined at a threshold drainage value. The DEM algorithm produces a dendritic network with unique downstream flow paths. There is no divergence in downstream flows. Streams defined from a DEM are subject to the spatial resolution and accuracy of the sampled elevation data.

The available digtial geospatial data sets of mapped stream networks are mostly derived from aerial photography. The EPA River Reach Files give a spatial representation of channel network hydrology for the entire United States. The most recent version, RF3, is detailed at a map scale of 1:100,000. A project is currently underway in Texas to build a spatial stream network data set at a uniform 1:24,000 map scale (Boghici, 1999). The recent availability of topographic maps and aerial photography in digital form at large map scales also raises the possibility of augmenting existing digital mapped stream networks of smaller scale by one or more of the methods suggested by Bauer.

1.3.2 Determining Hydrological Parameters with GIS

Maidment (1991) describes three methods of linking GIS and hydrological models: using GIS to read hydrological parameters, developing hydrological model parameters within GIS, and imbedding hydrological models within GIS. The relationship between GIS and hydrological models has evolved from the first method to the third. The first method, hydrological parameter determination, simply uses GIS to read parameters from existing data sets. This is a straightforward application of a GIS system to extract spatial data. In the second method, hydrological parameters are developed from basic data sets. In other words, basic spatial data sets are processed within the GIS according to programmed assumptions and algorithms. CRWR Prepro may be classified under the second method. The GIS interface developed in this research also falls into this category. This use of GIS is relatively well established.

Addressing this type of GIS-model linkage, Grayson, et. al. (1993) make the point that GIS is "hydrologically neutral" to the models. The GIS itself cannot generate hydrological information. GIS can only process the measured information provided in spatial data sets. It is tempting to try to "generate" new data through the interpolation and geographic manipulation features provided by GIS. The information content of interpolated information is only increased, however, if underlying physical relationships are present and are defined.

Research into coupling GIS and hydrological models often focuses on developing the functionality in GIS to calculate parameters and not on the applicability of the results. It is the GIS modeler's responsibility to make sure that output parameters are honestly described in terms of their source accuracy. Clark (1993) asserts that modelers are far less demanding of error assessment in GIS applications than would otherwise be the case. This may be due in part to what Clark describes as the "seductivity" of GIS display capabilities. Clark defines six measures by which the quality of source data may be judged : accuracy, precision, reliability, data documentation, information flow, and data version management.

> **Accuracy** specifies the extent to which recorded attributes faithfully represent the variable that is of interest…**Precision** indicates the resolution (potential and achieved) of the measurement process, and is affected by instrument characteristics, operator characteristics and spatial temporal sampling characteristics…**Reliability**…focuses on objectivity, since it is generally (but not necessarily correctly) assumed that an objective measure is more reliable than a subjective measure…Full reliability requires documentation of instrumentation, sampling design, and operator/observer characteristics… **Data documentation** determines the extent to which it is possible to identify data quality subsequent to the time of observation…**Information flow**… may introduce rounding, classification or generalization errors, some of which may be significant…**Data version management** [is necessary to avoid] the concurrent use of different data versions (Clark, 1993).

Grayson, et.al. (1993) point out a problem in combining GIS data and hydrological models based on scale. In this case, they are referring to the application of hydrological models derived from laboratory and research area catchments to studies with spatial data for regional areas. The curve number model used to distribute flows in this project is assumed to be applicable in this regard. In this study, however, the parameters (drainage area, curve number, and mean annual precipitation) are calculated from data sets produced at one map scale and applied to catchments of several scales. Drainage areas in this case study (and typically in the other river basins) range from 0.01 mi^2 to 3500 mi^2. The drainage areas are defined at a map scale of 1:24,000. The curve number and precipitation parameters, however, are taken from source data sets defined at smaller map scales. In the terrain data used to delineate the drainage areas, elevation values are defined approximately every 30 meters. The curve number values are calculated from USGS Land Use and Land Cover (LULC) and State Soil Geographic Database (STATSGO) soil data sets that sample data attributes approximately every 90 meters. The precipitation data has values every 250 meters, but the precipitation coverage is not meant to be accurate for point estimates. The precipitation data is generated from interpolating widely spaced rain gage data based on a regression model developed at Oregon State University. The metadata for the original precipitation grid states that while "point precipitation can be estimated at a spatial precision no better than 2km", "the overall distribution of precipitation features is thought to be accurate" (Daly, 1998). Some of the drainage areas defined in this study easily fit inside one cell of the original precipitation grid.

No studies were found evaluating GIS processed precipitation parameters, but one previous study by Bondelid, et. al. (1981) did compare curve numbers calculated from 1:250,000 scale USGS LULC data and 1:250,000 scale LANDSAT imagery with curve numbers calculated from locally available 1:24,000 scale map products for the same watersheds. This study looked at three basins with a total of 53 sub-watersheds ranging from 0.16 $mi.^2$ to 6.5 $mi.^2$ in area. For each sub-watershed, the authors compared the curve numbers prepared from a conventional method (using aerial photography and detailed soil surveys), with those prepared from analysis of 1:250,000 USGS digital land cover maps. The 1:250,000 scale source data was resampled to a 1:24,000 scale. The resulting curve number values from the USGS land cover and LANDSAT sources were found to generally agree well with the conventionally derived curve numbers. The authors note, however, that "significant loss in precision occurs in heterogeneous [curve number] regions with small sub-areas" (Bondelid, et.al, 1981). This caution is supported by a NRCS description of the STATSGO soils data, which states that "the level of mapping is designed to be used for broad planning and management uses covering state, regional, and multi-state areas" (USDA, 1999).

Previous projects have relied on the use of 1:250,000 DEMs to delineate watersheds. No previous studies were found, however, that judge the accuracy of this data source in defining small sub-watersheds. The widespread availability of 1:24,000 DEMs is relatively recent. No studies were found evaluating drainage areas produced from this data source. One general rule can be stated from the previous work; that an Albers map projection is used to preserve correct area when delineating watersheds.

1.4 CASE STUDY AREA

The Sulphur River, shown here in Figure 1.4, is a tributary of the Red River located in Northeast Texas. The basin was selected as the first to be modeled under the WAM project. It has the advantage of being relatively small in physical area, approximately 3,600 mi.^{2}, and having relatively few WRAP model components, 82 control points. The Sulphur basin is, as yet, the only basin model to be completed under the WAM program. It is used throughout this thesis as a case study in developing the geospatial database and processing the flow distribution parameters for a river basin. While this work was underway, several other river basins have been modeled, and the procedures have been updated from those originally used in developing the Sulphur basin data. The methodology presented in this report is the most current.

Figure 1.4 : The Sulphur River Basin

1.5 REPORT OUTLINE

This project marks the first time that geospatial data has been used to provide input parameters for flow distribution in a water availability model. A unique method of digital stream definition is presented, modifying digital elevation source data with digital representations of mapped stream networks.

This thesis is divided into five chapters and four appendices. Chapter two describes the development of the geospatial database used in the project, the first research objective. Chapter three details the methodology used in preparing the flow distribution input parameters, the second research objective. Chapter four discusses the results obtained from the case study in the Sulphur River Basin. The third research objective, accuracy of drainage areas, is discussed in this chapter. Chapter five presents the conclusions drawn from this work and provides direction for future work. Appendices A and B are applied exercises based on a sub-watershed of the Sulphur Basin. Appendix A is an exercise in applying the methodology presented in Chapter three to develop flow distribution parameters for control points in the exercise area. Appendix B applies the WRAP model to prepared input data for the exercise control points. Two compact discs containing all of the data referenced in this work are enclosed with this thesis. Appendix C provides a data dictionary of the geospatial coverages provided on each of these CDs. Appendix D contains the programming code used in the work : the individual ArcView Avenue scripts which together make up the WRAP Parameters GIS interface, and the ArcInfo macros used in building some of the data sets.

Chapter 2 : Data Description

2.1 MAP PROJECTIONS

Map projections transform a point on the earth's surface, referenced with geographic coordinates of latitude and longitude (ϕ,λ), into a point on a map, referenced with planar coordinates (x, y). Geographic coordinates depend on the reference shape (sphere or ellipsoid) that is used to simulate the earth. Common reference shapes are called earth datums. Map projections and datums must be clearly understood when working with geospatial data. While ArcView will display any given set of shapefiles, they will not be uniformly spatially referenced unless the datum and projection of each are the same. ArcInfo allows users to transform coverages from one datum and projection to another.

Locations and areas on the earth's surface define geometric properties of shape, area, distance, and direction. The process of projecting these locations and areas from the earth's surface onto a planar map will distort one or more of these properties. Certain map projections preserve some of these properties while distorting others. A conformal projection preserves local shape, while distorting area. An equal-area projection preserves area, while distorting shape, direction, and distance. Three specific map projections are used in this research : Albers Equal-Area, Lambert Conformal Conic, and Universal Transverse Mercator (UTM). Maidment (1998) gives a thorough description of these map projections. The actual parameters for each of the projections used in this project are given in Table 2.1.

Maps must also have a coordinate system describing the origin and map units of the planar coordinates. Agencies in Texas use a common map projection and coordinate system, the Texas State Mapping System (TSMS). The TSMS is a Lambert projection. The WAM project requires that all of the final ArcView shapefiles developed for the project be provided in a TSMS Lambert projection for standardization with other Texas map products. For hydrologic modeling, however, an Albers projection is frequently used, due to its property of preserving true area. In rainfall-runoff modeling, drainage area is often the most important parameter in determining volumes. Therefore, most of the shapefiles used in this project are initially created in an Albers projection of the TSMS, called TSMS Albers. Finally, the UTM system is used in this project when working with Digital Raster Graphics (DRGs). These files are originally in a UTM projection, and the number of files along with their large file size makes projection into TSMS Albers a lengthy procedure. So far, it has proven more timely to project other shapefiles into UTM when working with the DRGs. Texas is spread across three different UTM zones, shown in Figure 2.1.

Parameters	**TSMS Albers**	**TSMS Lambert**	**UTM**
Projection	Albers	lambert	utm
Zone	none	none	13, 14, or 15
Datum	NAD 83	NAD 83	NAD 27
Spheroid	GRS 1980	GRS 1980	Clarke 1866
Units	meters	meters	meters
Parameters :			
Reference Latitutde	31 10 0.000	31 10 0.000	none
Central Meridian	-100 0 0.000	-100 0 0.000	none
Standard Parallel 1	27 25 0.000	27 25 0.000	none
Standard Parallel 2	34 55 0.000	34 55 0.000	none
False Easting	1000000	1000000	none
False Northing	1000000	1000000	none

Table 2.1 : Map Projection Parameters used in the WAM project

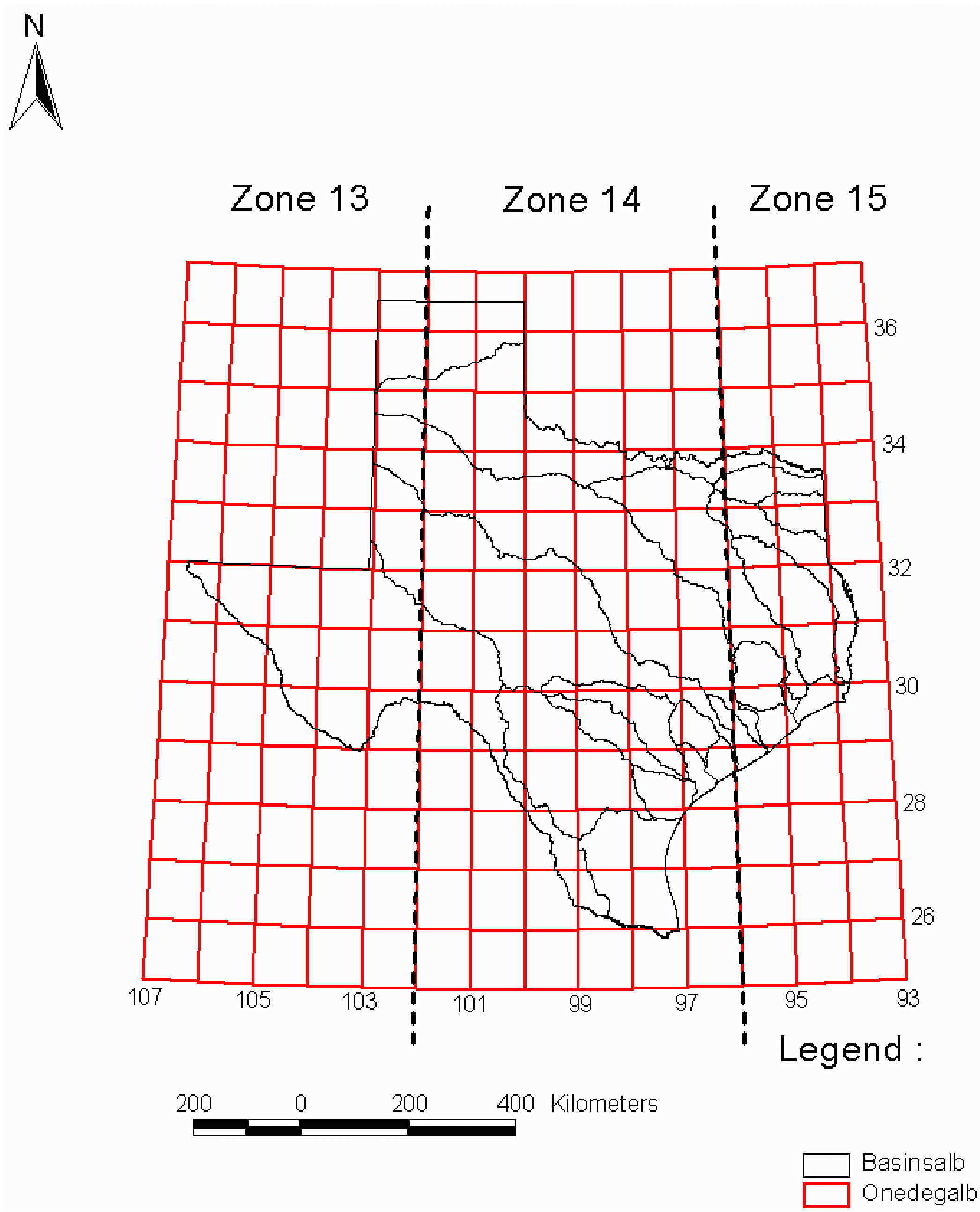


Figure 2.1 : UTM Zones in Texas

2.2 WRAP PARAMETERS GUI OVERVIEW

The WRAP Parameters interface is an ArcView version 3.1 project file, “wrap1117.apr,” with a set of specialized Avenue scripts embedded in it. Hardcopy of each Avenue script is provided in Appendix D. These scripts have all been linked to a set of customized View menus, "WRAP Parameters" and "WRAP Tools," and a set of View tools. The menu items and tools are briefly introduced here. The use of each specific function is explained in more detail throughout Chapters two and three as the project procedures are discussed. The user can gain more familiarity with the interface by completing the exercise in Appendix A.

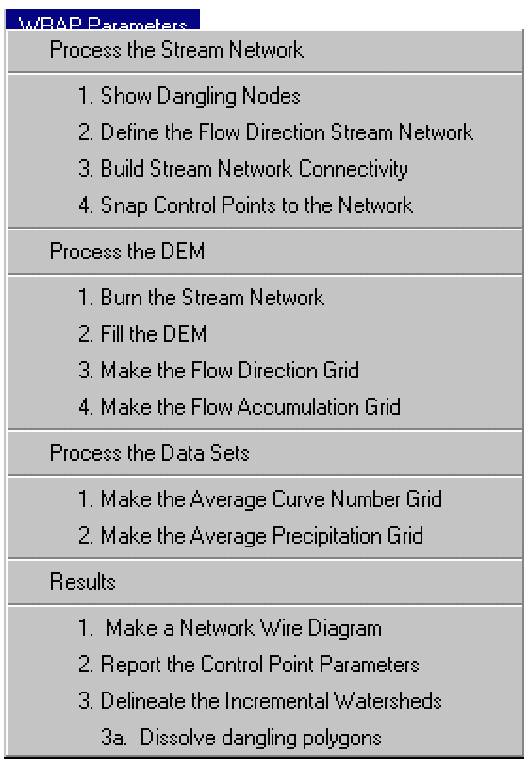


Figure 2.2 : WRAP Parameters Menu

Menu Item	Script	Description
Show Dangling Nodes	Wrap.dangle_menu	For the active stream network theme, outputs all dangling nodes in the view extent, either as a new theme or as graphics
Define DEM Stream Network	Wrap.demStreams	For a selected stream network theme, returns a line theme where each polyline is the flow direction path from one headwater (dangling) node to the basin outlet
Build Stream Network Connectivity	Wrap.streamSort	For a correctly defined stream network line theme, assigns each arc an ID number and recognizes the ID number of the next downstream arc
Snap Control Points to Network	Wrap.snapcp_menu	Snaps control point theme to stream network line theme (with connectivity). Display should be zoomed out well past the extent of the stream network
Burn Stream Network	Wrap.burn	Burns the DEM with the selected stream network
Fill DEM	Wrap.filldem	Fills sinks in the burned DEM
Make Flow Direction Grid	Wrap.fdr	Computes the flow direction grid
Make Flow Accumulation Grid	Wrap.fac	Computes the flow accumulation grid
Make Average Curve Number Grid	Wrap.avgcn	Computes the average curve number grid from the curve number and flow accumulation grids

Table 2.2 : WRAP Parameters Menu Description

Menu Item	Script	Description
Make Average Precipitation Grid	Wrap.avgpcp	Computes the average precipitation grid from the precipitation and flow accumulation grids
Make Network Diagram	Wrap.network	For a control point theme snapped to a connected stream network theme, draws a polyline from each control point to the downstream control point
Control Point Parameters	Wrap.parameters	For a control point theme, returns a duplicate theme with values for drainage area, curve number, and precipitation (read from the respective grids)
Delineate Incremental Watersheds	Wrap.watersheds	Delineates the incremental watersheds for each control point, outputs as polygon theme
Dissolve Dangling Polygons	Wrap.dissolve	Apply to watershed polygon theme to dissolve small isolated polygons

Table 2.2 : WRAP Parameters Menu Description

Figure 2.3 : WRAP Tools Menu

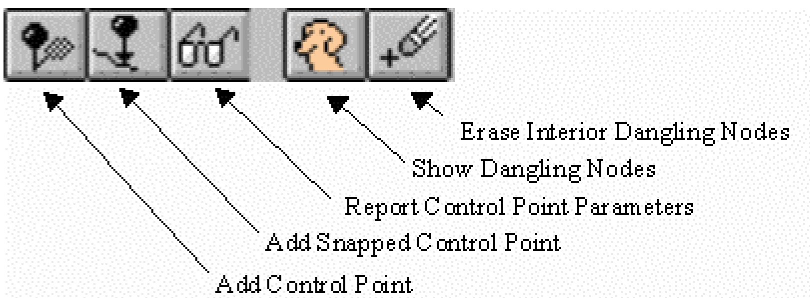


Figure 2.4 : WRAP Parameters Toolbar

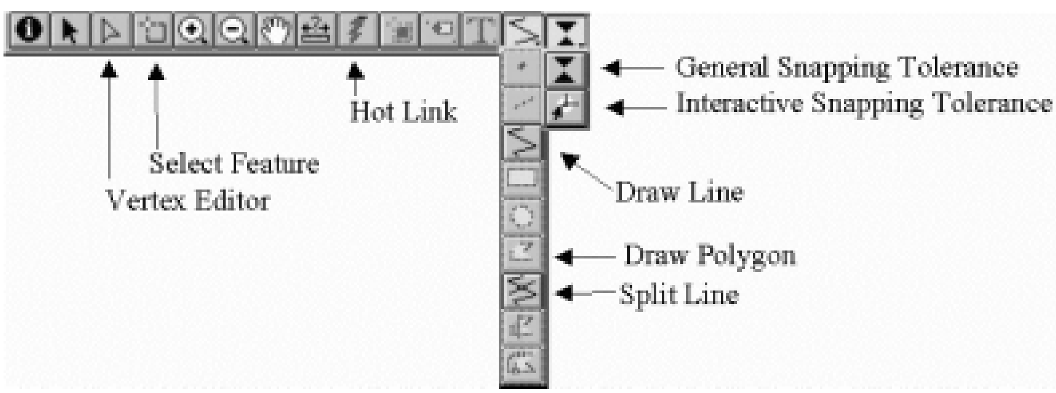


Figure 2.5 : ArcView Editing Tools

Menu Item	Script	Description
Add Lat/Longs	Wrap.addLat-Longs	Adds latitude and longitude coordinates (in decimal degrees) to a projected point coverage.
Merge Themes	Wrap.mergethemes	Merges selected themes of the same feature class. Only common attribute fields are retained.
Set Control Point Theme Names	Wrap.setCP	Sets the shapefile names used by the “Add Control Point” and “Add Snapped Control Point” tools
Set DRG File Path	Wrap.setDRG	Sets the directory path used by “wrap.addtopo” script to locate the DRG files
Set Parameter Grid Theme Names	Wrap.setGRid-Names	Sets global variables identifying the parameter grids.
Strip Fields	Wrap.stripfields	Deletes all but selected fields from an attribute table
Average Grid by Polygons	Wrap.avggrid-bypoly	Averages cell values of a grid within the boundaries of a polygon theme. Adds the averaged values as a new field in the polygon attributes.
Clip Grid by Polygon	Wrap.clipgrid-bypoly	Clips a grid with selected polygon(s). To clip the extent of the grid set the Analysis Extent to the extent of the selected polygons
Resample Grid	Wrap. resample	Resamples cell size of selected grid.

Table 2.3 : WRAP Tools Menu Description

Tool	Script	Description
Add Control Point	Wrap.addcp_tool	Adds a control point to the control point theme. ID must be an integer
Add Snapped Control Point	Wrap.snapcp_tool	Snaps a user input control point to a selected arc in the stream network.
Report Control Point Parameters	Wrap.parameters_tool	Calculates control point parameters at a user-entered point
Show Dangling Nodes	Wrap.dangle_tool	Shows the dangling nodes in the display extent of the active line theme
Erase Interior Dangling Nodes	Wrap.cleannet_tool	Removes a dangling node formed by snapping the endpoint of one arc in the middle of another arc. The original arc is split at the endpoint.

Table 2.4 : WRAP Parameters Toolbar

The standard ArcView editing tools highlighted in Figure 2.5 are also used throughout the project. Detailed explanations of these tools can be found in the ArcView help files and standard reference manuals.

2.3 GEOSPATIAL DATABASE

The following sections of this chapter describe the basic geospatial data coverages created in building a river basin database. Several of these coverages are clipped from larger state or regional coverages. These state coverages are not described in detail, unless they were built specifically for the WAM project. Most of the data sets are built as ArcInfo coverages and then transformed into ArcView shapefiles. Most of the processing steps can be done in either the ArcInfo or ArcView environment. They are presented here as originally developed, using ArcInfo in most cases.

Some conventions are used in detailing the procedures for each coverage. The software environment is indicated in italics followed by the command or action in bold print. Shapefile/coverage names are given in bold italics. Avenue scripts, Arc Macro Language (AML) codes, and GUI menu items and tools are referred to by their names in quotation. Throughout this thesis readers are assumed to have a basic familiarity with both ArcView and ArcInfo.

2.3.1 Basin Boundary

A coverage of river basins in Texas, ***texbasalb***, was obtained from TNRCC. The individual basin is taken from this coverage.

ArcView : **In the View window, click on *texbasalb* theme, making it active**
ArcView : **Using the Select tool, select the basin polygon**
ArcView : **In View menu, "Theme," click on "Convert to Shapefile"**
ArcView : **Set the shapefile name to *sulbasalb01.shp***

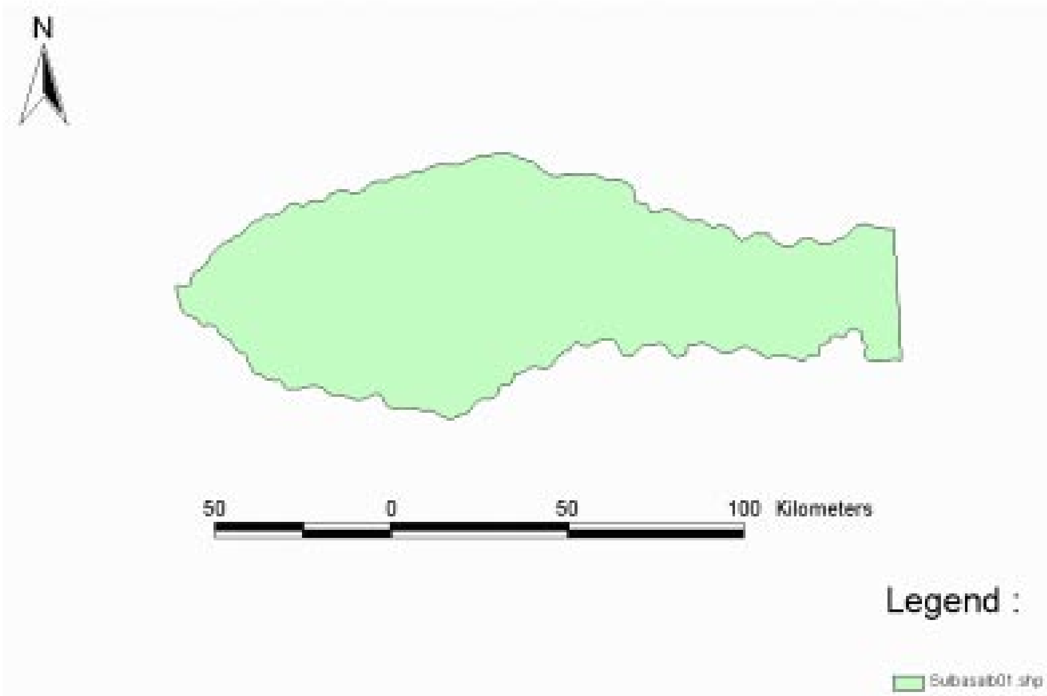


Figure 2.6 : Sulphur Basin Boundary Shapefile

2.3.2 Digital Raster Graphics

DRGs are scanned USGS 1:24,000 scale topographic maps. They provide a useful base for editing hydrography data and a tool for communicating specific locations to other persons in the project. DRGs may be obtained from The Texas Natural Resources Information System (TNRIS) or from the USGS. DRGs are packaged on CD-ROMs, with each CD containing the quad sheets for a 1°x1° latitude by longitude box.

Initially a list is made of all the DRGs in the river basin. This is done by overlaying the basin boundary shapefile, ***sulbasalb01.shp***, on a latitude/longitude coverage, ***onedegalb***, and a quadrangle coverage, ***quadsalb***. For easy reference, a layout may be made of this view. Figure 2.7 shows an example of this layout. The standard USGS naming convention for quadrangles is used in identifying DRG files. This convention is a concatenation of the longitude and latitude of the lower right corner of the 1°x1° box with an alphanumeric row and column identifier for the individual quad, and is illustrated in Figure 2.8. All DRG files in the basin are copied to a working directory.

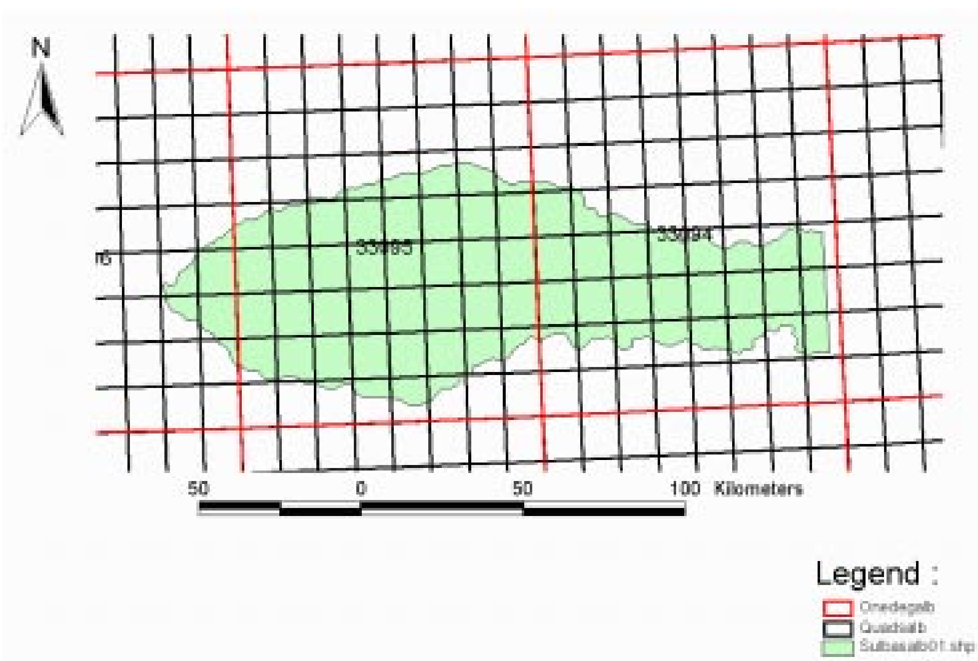


Figure 2.7 : Layout Showing Individual Quadrangles within the Basin

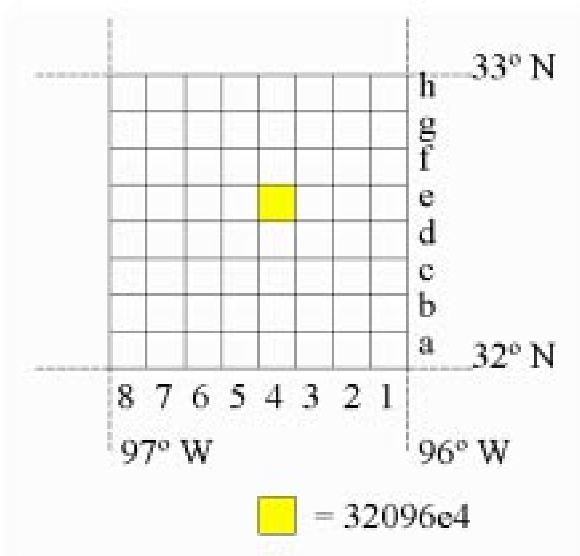


Figure 2.8 : USGS Quadrangle Naming Convention

DRGs are originally in a UTM map projection. Projecting the DRGs can be a time and computer-memory intensive task. During the course of this work, times of twenty minutes to two hours have been observed for projecting individual DRGs. When working with DRGs it is usually more convenient to simply project the other shapefiles into UTM and work with them in that projection. In some cases, however, it may be desirable to project some or all of the DRGs. In the Sulphur basin, for example, 76 DRGs are required to cover the basin area. Six of these DRGs are in UTM zone 14, the remainder in UTM zone 15. Rather than work in two UTM projections (which may be simpler in very large basins, such as the Brazos) the six UTM zone 14 DRGs are projected to UTM zone 15.

Projecting DRGs is a bit more complex than projecting coverages. Each image file is first converted to a grid. The grid is projected and converted back into an image file. The specific commands for doing this are contained in the ArcInfo AML, "reprodrg.txt." in Appendix D. This AML can be applied to any set of DRGs by editing the image filenames in the AML text file.

Arc : **&run reprodrg.txt**

Since the DRGs remain in a UTM map projection, the basin boundary should be projected to UTM for reference. The user should make sure the correct UTM zone is contained in the projection file "albtoutm.txt." When converting the UTM basin coverage back to a shapefile, some extra steps must be taken. The version of ArcInfo used in this work, 7.2.1, will only allow coverages to be converted to shapefiles with a standard 8.3 character filename. ArcInfo 7.2.1 also requires field names to be unique within ten characters. These limitations are bypassed by making a copy of the UTM coverage with a shortened coverage name. ArcView may then be used to rename the resulting shapefile with the WAM standard filename.

Arc : **shapearc *sulbasalb01 sulbasalb***
Arc : **build *sulbasalb***
Arc : **project cover *sulbasalb sulbasutm* albtoutm.txt**
Arc : **build *sulbasutm***
Arc : **copy *sulbasutm sultmp***
Arc : **arcshape *sultmp* poly *sultmp***
Arc : **kill *sultmp* all**
ArcView : **In View menu "File," click on "Manage Data Sources"**
ArcView : **Rename *sultmp.shp* as *sulbasutm01.shp***

Each DRG file contains the complete image of the map including the map collar. This is a hindrance when working with more than one DRG at a time as the map collars overlay the neighboring DRGs. The USGS has procedures available for completely removing the map collar from these files. This information is available on-line at ftp://ftpmcmc.cr.usgs.gov/release/drg/clip. Due to the processing time required to remove the map collars from all the quads in a river basin, Jóna Finndís Jónsdóttir, a research assistant at CRWR, developed a procedure of simply displaying each file with the map collar masked.

The shapefile ***texmesutm15.shp*** may be used to establish a hot link in ArcView between the quadrangle polygons and the individual DRG files. Upon establishing this link, each DRG can be automatically called up and masked simply by clicking on the desired quad in ***texmesutm15.shp*** with the "Hot Link" tool. This is accomplished by the script, "wrap.addtopo." Figure 2.9 shows multiple DRGs added to a View window in ArcView using the "wrap.addtopo" script.

The WRAP Tools menu item "Set DRG File Path" is used to set the path to the directory containing the DRG files. This menu item executes the script "wrap.setDRGpath" asking the user to enter the full path name for the directory containing any DRGs that are to be hot linked. The hot link properties of a theme are set in ArcView as follows :

ArcView : **In the View window, click on *texmesutm15.shp*, making it active**
ArcView : **In View menu "Theme," click on "Properties"**
ArcView : **Click on the Hot Link icon**
ArcView : **Set Field = "Code," Predefined Action = "Link to User Script," and Script = "wrap.addtopo"**

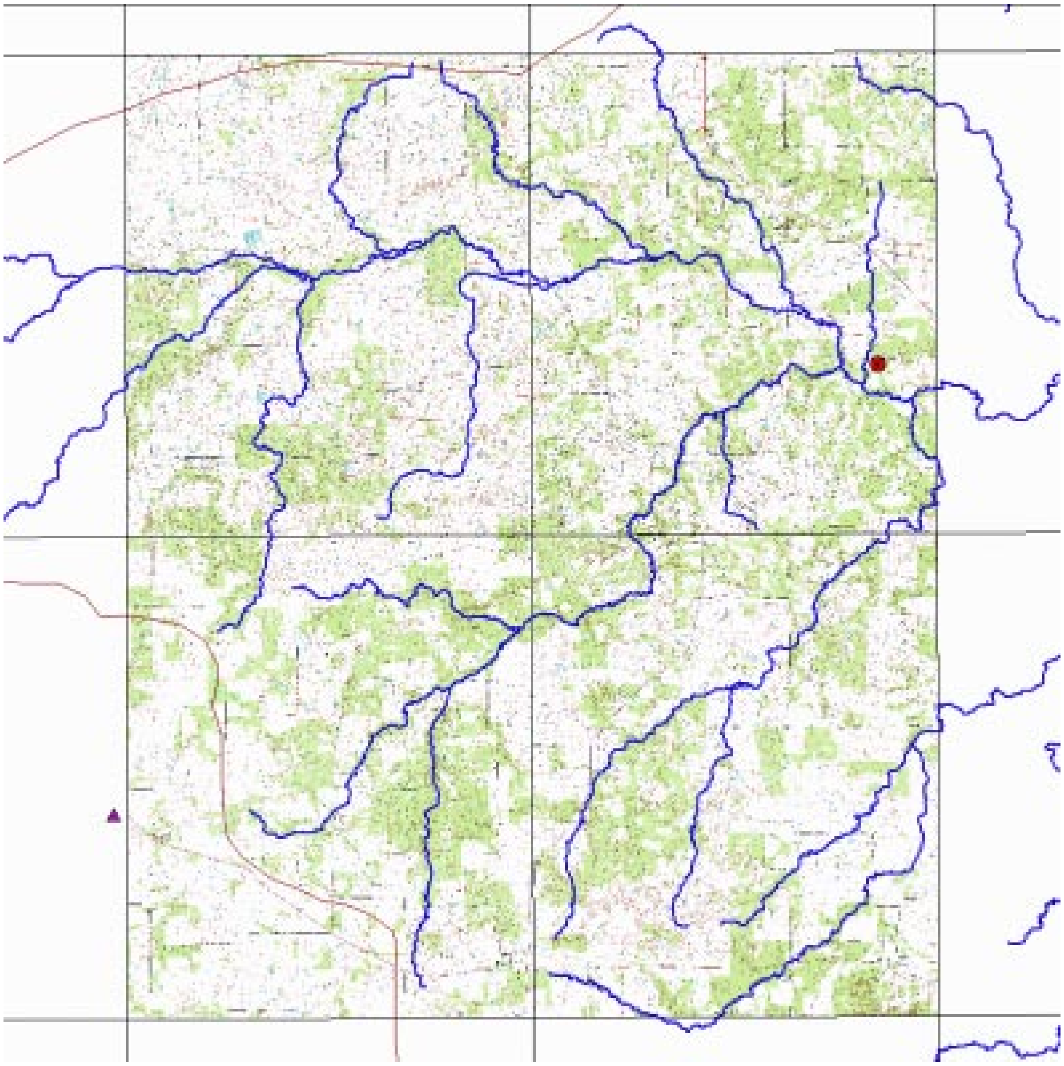


Figure 2.9 : Multiple DRGs Viewed with "Addtopo" Script (Jónsdóttir, 1999)

2.3.3 Digital Elevation Model

USGS Digital Elevation Models (DEM) are grid representations of cartographic elevation data made by taking point elevations at regularly spaced intervals. There are three scales of DEMs available : small (1:250,000), intermediate (1:100,000), and large (1:24,000). When this project began, small scale DEM data was the only consistent source of elevation data available for the entire state of Texas. Since then, however, large scale DEMs have become available for the entire state through the National Elevation Database (NED) program. A small scale DEM was originally used in the processing of the Sulphur basin, and the procedure for producing small scale DEMs is discussed here. The use of large scale DEMs is discussed in Chapter 4.

1:250,000 DEM data is available for download from the USGS internet site at : http://edcwww.cr.usgs.gov/doc/edchome/ndcdb/ndcdb.html. The DEM data is available in 1°x1° tiles which are named from the corresponding standard U.S. 2°x1° 1:250,000 map sheets. While there are several options for downloading, the method used here is as follows. A layout of counties within the river basin is prepared, similar to the quad layout shown in Figure 2.7, using the ***texctyalb*** coverage and the ***sulbasalb01.shp*** shapefile. From the USGS web site, the option "FTP via Graphics" is selected under the 1:250,000 DEM category. This brings up a map, where by zooming in on the desired region, a map overlaying the 1°x1° DEM tile borders on state counties is obtained. Using the layout of counties in the river basin as a guide, all necessary 1°x1° tiles are identified and downloaded.

For the Sulphur basin, eight tiles are required : eldorado-w, texarkana-e, texarkana-w, sherman-e, dallas-e, tyler-w, tyler-e, and shreveport-w. The compressed files are downloaded to save time. These files are downloaded in gunzip (.gz) format, and may be extracted with the gunzip command in a Unix environment, or simply extracted with WinZip. WinZip asks for the filename contained in the archive; it is just the filename minus the ".gz" extension.

Each DEM must first be coverted from an ASCII DEM file into an ArcInfo grid.

Arc : **demlattice *sherman-e sherme***

Each grid is then converted from a floating point to an integer grid. This dramatically reduces the file size and the processing time required in subsequent steps. As a floating point grid, the Sulphur basin DEM requires 13.2 megabytes of storage space. Converting the DEM to an integer grid reduces this to 2.5 megabytes. The elevation data is initially stored as floating point values with units of meters. Simply converting this directly to an integer grid loses some of the elevation information contained in the decimal places of the floating point values. To maintain a greater degree of accuracy in the integer grids, the floating point grids are first multiplied by 100. The resulting integer grid has elevation units of centimeters.

Arc : **grid**
Grid : ***shermecm* = 100 * *sherme***
Grid : ***shermein* = int (*shermecm*)**

The individual grids are then be merged.

Grid : ***suldemgeo01* = merge (*eldorwin, texarein, texarwin, shermein, dallaein, tylerwin, tylerein, shrevwin*)**
Grid : **quit**

All of the intermediate grid products are deleted with the "kill all" command. For large basins, it may be helpful to execute these commands as an AML.

The merged grid, ***suldemgeo01***, is then clipped to some extent beyond the basin boundary. This is necessary to ensure that watersheds defined from the DEM are based on the DEM data and not limited by the basin boundary shapefile (the actual source of the Texas river basins shapefile from TNRCC is not known, but it was likely derived from hand-delineated map products). Experience at CRWR has shown 10,000 meters to be a reasonable buffer width.

The polygon of the basin boundary is first buffered by 10 km. The buffered coverage is then projected from the TSMS Albers projection to the geographic DEM projection. USGS 1:250,000 DEMs are initially in a geographic projection with the WGS72 datum and spheroid. The most accurate method of projecting coverages between WGS and NAD datums uses the NAD83 equivalent datum keyword, "NAR_C" (ESRI, 1998). NAR_C is equivalent to NAD83, and the projection file of a coverage can be updated to show this using the "projectdefine" command.

Arc : **buffer *sulbasalb sulbufalb* # # 10000 #**
Arc : **projectdefine cover *sulbufalb***
Project : **projection Albers**
Project : **datum nar_c**
Project : **spheroid GRS1980**
Project : **units meters**
Project : **parameters**
1st standard parallel : **27 25 0.000**
2nd standard parallel : **34 55 0.000**
central meridian : **-100 0 0.000**
latitude of projection's origin : **31 10 0.000**
false easting (meters) : **1000000**
false northing (meters) : **1000000**
Arc : **project cover *sulbufalb sulbufdem* albtodem.txt**
Arc : **build *sulbufdem***
Arc : **grid**
Grid : **mapex *sulbufdem***
Grid : **setwindow *sulbufdem***
Grid : ***tempdem1 = suldemgeo01***
Grid : ***tempdem2* = selectpolygon(*tempdem1, sulbufdem,* inside)**
Grid : **quit**

Finally, the resulting grid must be projected to TSMS Albers. The projected grid ***suldemalb*** will have its datum listed as "NAR_C." This can be changed to read "NAD83" using the "projectdefine" command as above.

Arc : **project grid *tempdem2 suldemalb* demtoalb.txt**
Arc : **kill *sulbufdem* all**
Arc : **kill *suldemgeo01* all**
Arc : **kill *tempdem1* all**
Arc : **kill *tempdem2* all**

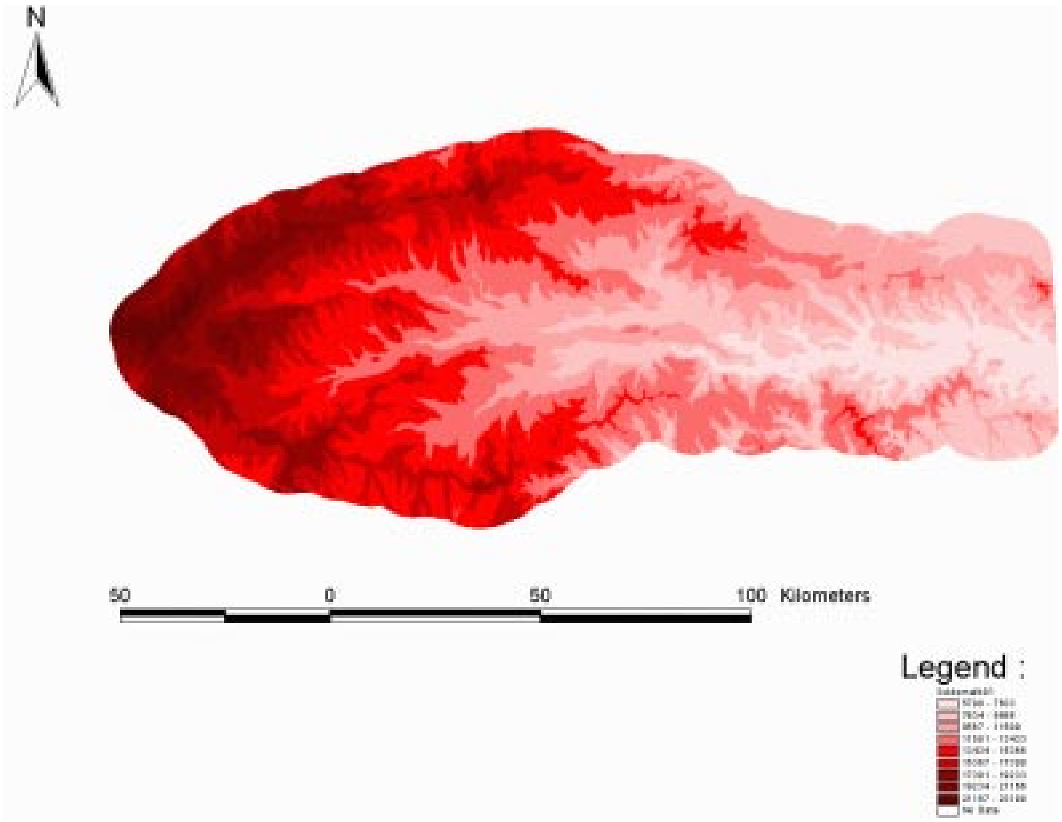


Figure 2.10 : 1:250,000 Scale DEM of the Sulphur Basin

2.3.4 EPA Reach Files, Version 3.0

The United States Environmental Protection Agency's (EPA) Reach Files, Version 3.0 (RF3) represents the most detailed hydrographic information uniformly available in the U.S. at present. RF3 was developed from the USGS 1:100,000 scale Digital Line Graph (DLG) hydrography data. An extensive database of stream segment attributes was added to the geographic stream locations. RF3 is available for download from the EPA's Office of Science and

Technology BASINS project internet site at :

http://www.epa.gov/OST/BASINS/download.htm.

From this site, RF3 data may be downloaded for each 8 digit Hydrologic Unit Code (HUC8). The HUC8s comprising the river basin and its borders are identified by overlaying the river basin boundary shapefile, ***sulbasalb01.shp***, onto a coverage of HUC8s in Texas, ***texhucalb***, in a manner similar to the previous layouts, as shown in Figure 2.11.

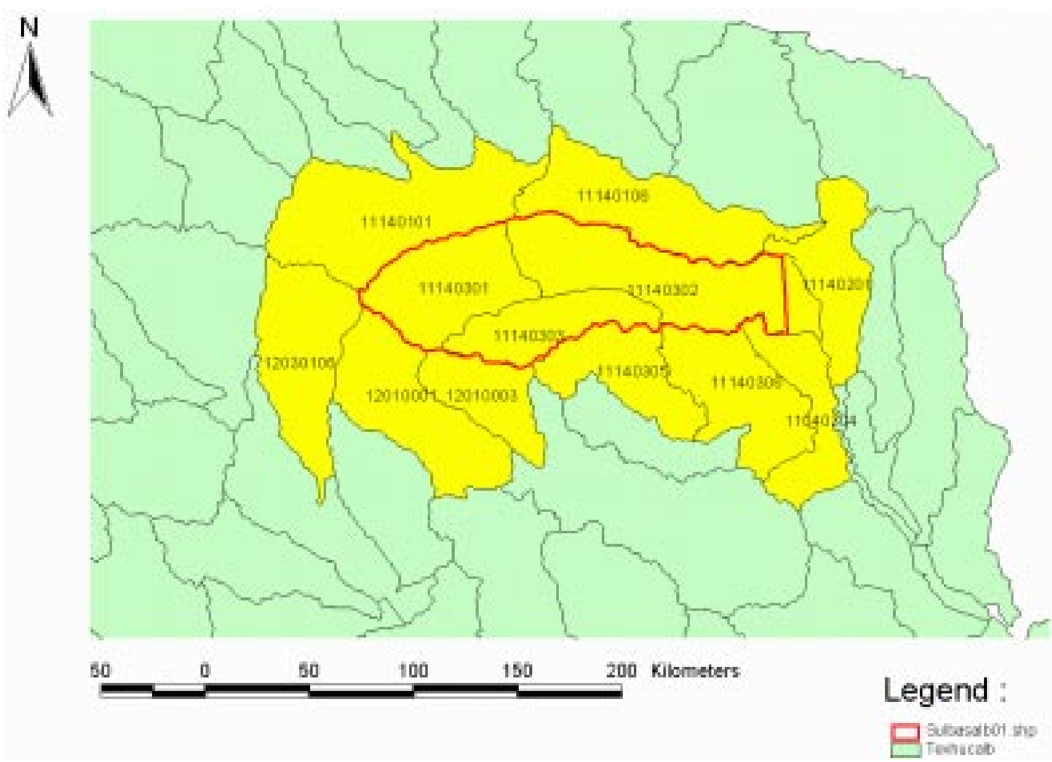


Figure 2.11 : Selected HUCs for RF3 Download

Twelve HUCs are needed to cover the Sulphur basin and surroundings : 11140101, 11140106, 11140201, 11140301, 11140302, 11140303, 11140304, 11140305, 11140306, 12010001, 12010003, and 12030106. For each HUC8, an executable (.exe) archive file is downloaded. Executing this file launches the WinZip Self Extractor which unzips the RF3 shapefile. Once the RF3 shapefiles are prepared for all HUC8s in the basin, they are merged using the WRAP Tools menu item, "Merge Themes." The RF3 shapefiles should be merged into two separate shapefiles : one shapefile containing all HUCs interior to the basin boundary, ***sulrfigeo01.shp***, and one containing all the HUCs exterior to the basin, ***sulrfegeo01.shp***. This separation of the RF3 stream segments is useful in the later project stages of stream editing and DEM hydrologic modeling. Both RF3 shapefiles of the basin are shown in Figure 2.12.

The original BASINS RF3 data is in a geographic projection. Both shapefiles should be projected to the UTM coordinate system. When copying line coverages, some of the field names are duplicated and must be deleted before the coverage can be converted to a shapefile. These fields are deleted from the arc attribute table using the "dropitem" command.

ArcView : **In View menu "WRAP Tools," click on "Merge Themes"**
ArcView : **Select all exterior HUC themes**
ArcView : **Set the shapefile name to *sulrfegeo01.shp***
ArcView : **In View menu "WRAP Tools," click on "Merge Themes"**
ArcView : **Select all interior HUC themes**
ArcView : **Set the shapefile name to *sulrfigeo01.shp***
Arc : **shapearc *sulrfegeo01 sulrfegeo01***
Arc : **shapearc *sulrfigeo01 sulrfigeo01***
Arc : **project cover *sulrfegeo01 sulrfeutm01* bastoutm.txt**
Arc : **project cover *sulrfigeo01 sulrfiutm01* bastoutm.txt**
Arc : **kill *sulrfegeo01* all**
Arc : **kill *sulrfigeo01* all**
Arc : **build *sulrfeutm01* line**
Arc : **build *sulrfiutm01* line**
Arc : **copy *sulrfeutm01 tmp1***
Arc : **copy *sulrfiutm01 tmp2***
Arc : **dropitem *tmp1.aat tmp1.aat***
Enter the 1st item : **fnode_**
Enter the 2nd item : **tnode_**
Enter the 3rd item : **lpoly_**
Enter the 4th item : **rpoly_**
Enter the 5th item : **end**
Arc : **dropitem *tmp2.aat tmp2.aat***
Enter the 1st item : **fnode_**
Enter the 2nd item : **tnode_**
Enter the 3rd item : **lpoly_**
Enter the 4th item : **rpoly_**
Enter the 5th item : **end**
Arc : **arcshape *tmp1* line *tmp1***
Arc : **arcshape *tmp2* line *tmp2***
Arc : **kill *tmp1* all**
Arc : **kill *tmp2* all**
ArcView : **In View menu "File," click on "Manage Data Sources"**
ArcView : **Rename *tmp1.shp* as *sulrfeutm01.shp***
ArcView : **Rename *tmp2.shp* as *sulrfiutm01.shp***

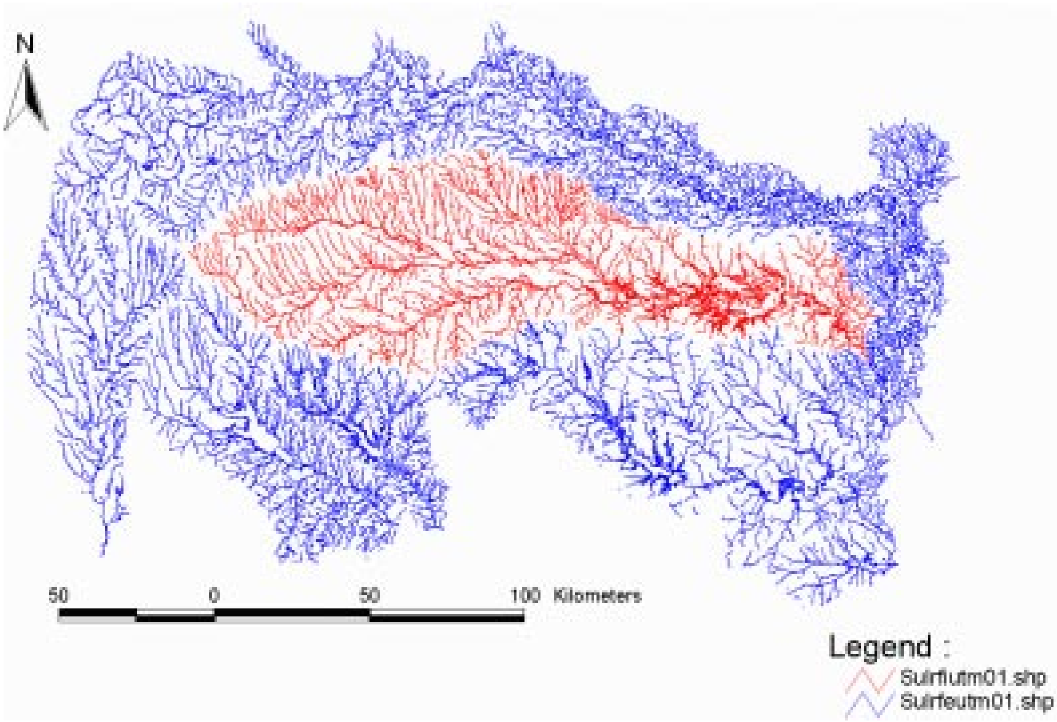


Figure 2.12 : RF3 Shapefiles of Sulphur Basin

2.3.5 USGS Centerlines

As part of the forthcoming National Hydrography Dataset (NHD), the USGS has developed digitized coverages of centerlines through open water bodies. This coverage was obtained from the USGS for hydrologic regions 11 and 12. These two coverages were originally in a standard U.S. Albers projection. They were then projected into UTM zone 15 and merged, creating the coverage, ***texctlutm***. The UTM projection is the most convenient for this data set as the centerlines are merged with the UTM RF3 shapefile. ***Texctlutm*** is clipped to the extent of the basin boundary and converted to a shapefile, ***sulctlutm01.shp***.

Arc : **clip *texctlutm sulbasutm sulctlutm01* line**
Arc : **copy *sulctlutm01 temp***
Arc : **arcshape *temp* line *temp***
Arc : **kill *temp* all**
ArcView : **In View menu "File," click on "Manage Data Sources"**
ArcView : **Rename *temp.shp* as *sulctlutm01.shp***

2.3.6 Base Stream Network

In addition to the WAM Project, CRWR is also working with TNRCC on a TMDL project with similar needs. Out of these projects, a concept has developed of creating and working with digital stream networks in the river basins. Stream networks are defined here as a digital representation of the surface hydrography as a series of oriented reaches, such that each reach connects to only one downstream reach. This concept was inspired in part by NHD, which will contain this type of stream network along with the additional attributes of RF3. Due to the WAM project schedule, however, it was necessary to go ahead and build this stream network manually, rather than wait for the release of the finalized NHD.

The base stream network is built from the ***sulrfiutm01.shp*** shapefile. RF3 contains a lot of detailed surface water features such as the shorelines of large open water bodies and small water bodies. These may be eliminated by querying the original RF3 shapefile to identify the true reaches. RF3 is extensively attributed. Documentation of RF3 attributes is available on-line from the EPA (EPA, 1996). One of these attributes, "Reachtype," describes the type of surface water feature with a single letter code. The desired reachtypes are : "R" (river reaches), “S” (start reaches), and “T” (terminal reaches). Figure 2.13 shows the result of this query on the Sulphur basin RF3 shapefile.

ArcView : **Click on *sulrfiutm01.shp* theme, making it active**
ArcView : **Click on the Theme/Query tool**
ArcView : **Query : ([Reachtype]=”R”) or ([Reachtype]=”S”) or ([Reachtype]=”T”)**
ArcView : **Query : Click on “New Set”**
ArcView : **In View menu “Theme,” click on “Convert to Shapefile”**
ArcView : **Set the shapefile name to *sulstputm01.shp***

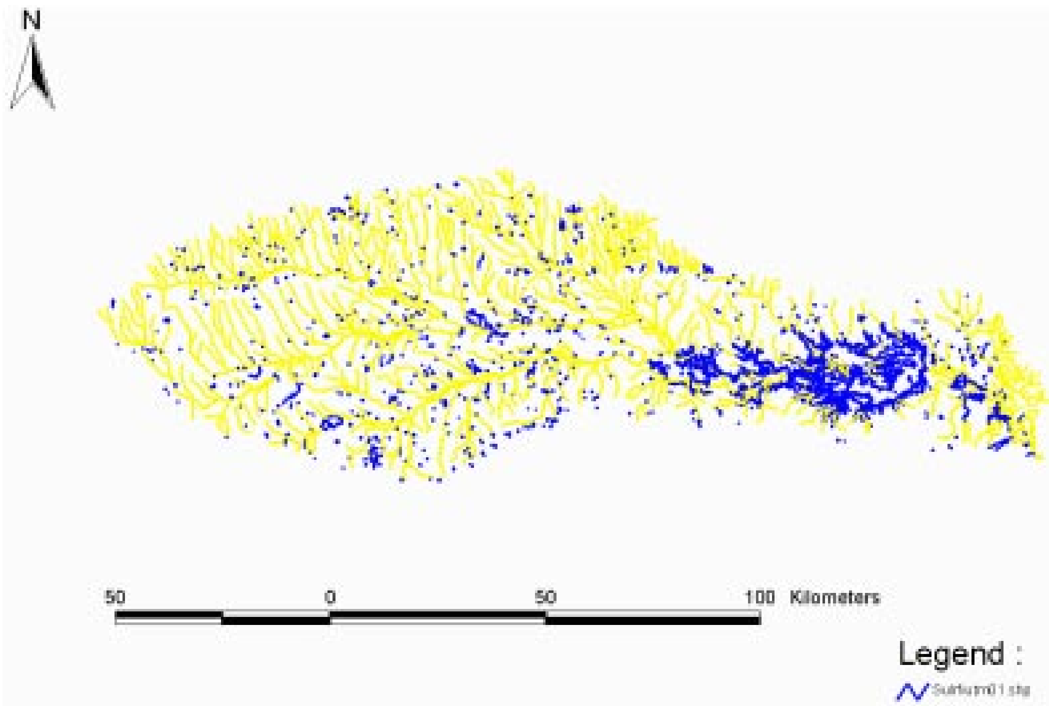


Figure 2.13 : RF3 Segments Selected by Reachtype Query

The RF3 attributes are now extraneous and may be removed from the theme attribute table. This will make the shapefile smaller and easier to process subsequently. The WRAP Tools menu item "Strip Fields" will remove all but selected fields from a shapefile. Only the "Shape" field and one other identifier field need be retained.

The USGS centerline shapefile, ***sulctlutm01.shp***, is merged with ***sulstputm01.shp***. The centerlines will fill most gaps left by the deletion of the RF3 open water features. Endpoints of the merged centerlines and existing reaches do not exactly match. This discontinuity will be addressed in the stream editing discussion in Chapter three.

ArcView : **In View menu "WRAP Tools," click on "Merge Themes"**
ArcView : **Select the themes : *sulstputm01.shp, sulctlutm01.shp***
ArcView : **Set the resulting shapefile name to *sulswvutm01.shp***

Figure 2.14 shows the base stream network produced for the Sulphur basin.

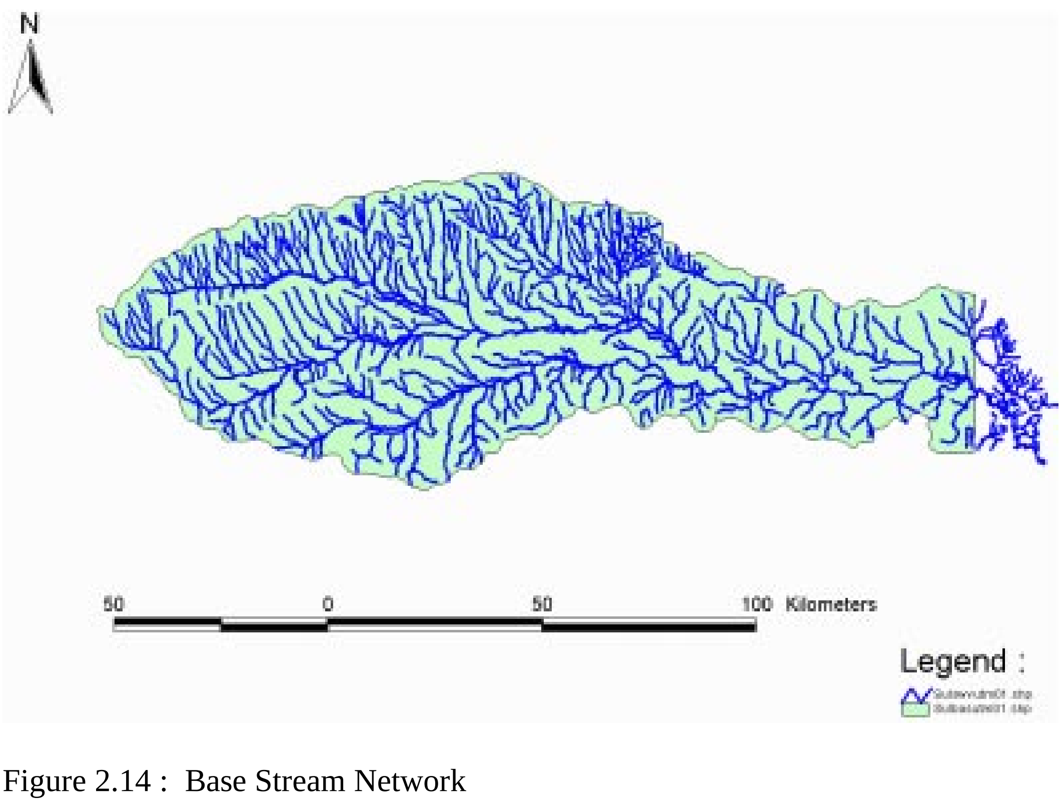


Figure 2.14 : Base Stream Network

The exterior stream shapefile is also processed. The exterior streams are used to condition the DEM, but it is not necessary that they conform to the stream network definition. The open water features do not need to be removed. The RF3 attributes are removed with the "Strip Fields" menu item. The theme is then clipped to an extent slightly larger than that of the DEM. The buffered basin boundary, ***sulbufalb01.shp***, is projected into UTM coordinates, and is buffered by a further 1,000 meters.

Arc : **shapearc *sulbufalb01 sulbufalb01***
Arc : **project cover *sulbufalb01 sulbufutm01* albtoutm.txt**
Arc : **buffer *sulbufutm01 sulbf2utm01* # # 1000 #**
Arc : **build *sulbf2utm01.shp***
Arc : **clip *sulrfeutm01 sulbf2utm01 sulswxutm01* line**
Arc : **build *sulswxutm01* line**
Arc : **copy *sulswxutm01 temp***
Arc : **arcshape *temp* line *temp***
Arc : **kill *temp* all**
ArcView : **In View menu "File," click on "Manage Data Sources"**
ArcView : **Rename *temp.shp* as *sulswxutm01.shp***

2.3.7 USGS Gage Locations

A point coverage of USGS gages in the basin is produced for later use as a guide in locating primary control points. The locations of all USGS gages in the state may be found on the state USGS internet site at http://txwww.cr.usgs.gov. Selecting "Online Hydrologic Databases" and then "Index of Gaging Stations by HUC" brings up a listing of all gaging stations in the state listed by HUC8. The location information of all gages in the basin is extracted from this listing. This information is first pasted from the web browser into a Word document, “gages.doc.” This is an example of the information extracted for one gage in the Sulphur River basin :

STATION 07342465 SOUTH SULPHUR AT COMMERCE, TX
Hunt County, Texas; Hydrologic Unit Code 111403
Latitude 33°12'42", Longitude 095°54'50"(MAP)
Drainage area 150.0 square miles

A spreadsheet is then created in MS Excel to transform the latitude and longitude coordinates into units of decimal degrees, as shown in Table 2.5. The following spreadsheet formulas are used to calculate decimal degrees :

$$Long(dd) = -e3 - f3/60 - g3/3600 \qquad (3.1)$$

$$Lat(dd) = b3 + c3/60 + d3/3600 \qquad (3.2)$$

	A	B	C	D	E	F	G	H	I
1	Station ID		lat			long		long(dd)	lat(dd)
2		deg	min	sec	deg	min	sec		
3	8177700	29	29	56	98	30	36	-98.510000	29.498889
4	8177800	29	28	24	98	28	26	-98.473889	29.473333
5	8177820	29	27	56	98	28	1	-98.466944	29.465556
6	8177860	29	27	4	98	28	42	-98.478333	29.451111
7	8177920	29	25	24	98	29	32	-98.492222	29.423333
8	8178000	29	24	34	98	29	41	-98.494722	29.409444
9	8178050	29	23	34	98	29	40	-98.494444	29.392778
10	8178565	29	19	19	98	27	0	-98.450000	29.321944
11	8178620	29	35	24	98	27	47	-98.463056	29.590000
12	8178622	29	34	58	98	27	36	-98.460000	29.582778
13	8178640	29	37	23	98	26	29	-98.441389	29.623056
14	8178645	29	37	4	98	25	41	-98.428056	29.617778
15	8178690	29	31	36	98	26	25	-98.440278	29.526667
16	8178700	29	30	57	98	25	51	-98.430833	29.515833

Table 2.5 : Gage Data Spreadsheet

The station ID and decimal degree latitude and longitude of each gage are then pasted into a new worksheet. This sheet is formatted to prepare an input file for the ArcInfo "generate" command. The cells in each column are formatted as follows : station ID (number, 0 decimals), Long (number, 6 decimals), and Lat (number, 6 decimals). The word "end" must be entered in the first cell of the row after the last gage entry. The worksheet is then saved as a comma delimited (.csv) file. The formatting of the file should be checked in a text editor. Make sure that the longitude values are listed first and have a negative sign (indicating a western longitude), delete the column headers, and delete any extra commas after the final "end." Save this file as a text file, "gages.txt." This text file is now properly formatted to generate a point coverage.

Arc : **generate *gages***
Generate : **input gages.txt**
Generate : **points**
Generate : **quit**
Arc : **build *gages* points**
Arc : **addxy *gages***

Some further processing is necessary to properly format the station ID attribute field. When the point coverage is generated by ArcInfo it is only allowed, by default, an ID field that displays 4 digits. The full ID strings are still there, however, and may be copied into a new field that is set to display 8 digits.

Arc : **additem *gages.pat gages.pat* station 4 8 B**
Arc : **arcplot**
Arcplot : **calculate *gages.pat* info station = gages-id**
Arcplot : **quit**

The coverage is then projected from a geographic projection to both the TSMS Albers and UTM projections. Although there is no documentation with the original gage coordinates, it is assumed that they were derived from topographic maps using the older NAD27 datum and clarke1866 spheroid.

Arc : **project cover *gages sulsglalb01* gagtoalb.txt**
Arc : **project cover *gages sulsglutm01* gagtoutm.txt**
Arc : **copy *sulsglalb01 tmp1***
Arc : **copy *sulsglutm01 tmp2***
Arc : **arcshape *tmp1* point *tmp1***
Arc : **arcshape *tmp2* point *tmp2***
Arc : **kill *tmp1* all**
Arc : **kill *tmp2* all**
ArcView : **In View menu “File,” click on “Manage Data Sources”**
ArcView : **Rename *tmp1.shp* as *sulsglalb01.shp***
ArcView : **Rename *tmp2.shp* as *sulsglutm01.shp***

Figure 2.15 in Section 2.3.9 shows the resulting gage shapefile along with the water right shapefiles for the basin.

2.3.8 Texas Water Rights Locations

A database of Texas water rights was obtained from the technical coordinator of the WAM project, Parsons Engineering Science. This database was itself taken from the records of the TNRCC Surface Water Quantity Division. The database was originally received as an MSAccess database. The database is extensively attributed and contains it’s own data dictionary. Individual water rights have multiple records in the database. Unfortunately, water rights are not as simple as just defining one geographic point per right. Many water rights have several records in the same location and/or multiple records in different locations. Fortunately, it is TNRCC’s task to sort out this database.

There are about 8,000 records in the database. A latitude/longitude coordinate is given for each record. A shapefile of these locations was produced to aid TNRCC in locating the actual diversion and return flow points associated with each water right. These original database locations are just general locations for each water right and are not used further in this work.

To build the shapefile it was necessary to assign each record a unique identification number. A field of unique values, "Unique," is present in the original database but it is incomplete, lacking values for about 300 of the records. The records missing a value in the Unique field were assigned values beginning with 10,000. This version of the Access database was then saved as a separate database file, "uniques.dbf." This file was used to create the point coverage, ***texwrdalb***, of all the water right records, in the same manner as presented in Section 2.3.7 for the USGS gages.

Texwrdalb is clipped with the basin boundary to extract only those records in the basin. The result, ***sulwrdalb01***, is projected into UTM for later use by TNRCC. Figure 2.15 in Section 2.3.9 shows these water right record locations, along with the USGS gages and water right diversion points in the basin.

Arc : **clip *texwrdalb sulbasalb01 sulwrdalb01* point**
Arc : **project cover *sulwrdalb01 sulwrdutm01* albtoutm.txt**
Arc : **copy *sulwrdalb01 tmp1***
Arc : **copy *sulwrdutm01 tmp2***
Arc : **arcshape *tmp1* point *tmp1***
Arc : **arcshape *tmp2* point *tmp2***
Arc : **kill *tmp1* all**
Arc : **kill *tmp2* all**
ArcView : **In View menu "File," click on "Manage Data Sources"**
ArcView : **Rename *tmp1.shp* as *sulwrdalb01.shp***
ArcView : **Rename *tmp2.shp* as *sulwrdutm01.shp***

The shapefile can be linked with the "uniques.dbf" database file, establishing a true geospatial representation of the water right records.

ArcView : **In Project window, click on "Tables" and "Add"**
ArcView : **Load the table "uniques.dbf"**
ArcView : **In table "uniques.dbf," select field "Uniques"**
ArcView : **In attribute table of *sulwrdutm01.shp*, select field "Wrights-id"**
ArcView : **In Table menu, "Table," click on "Join"**

2.3.9 TNRCC Water Right Diversion Points

TNRCC provides a shapefile of points representing the actual diversion and return points of each water right, ***sulwruutm01.shp***. In some cases, multiple shapefiles are provided by TNRCC. These may be merged into one shapefile using the WRAP Tools menu item, "Merge Themes." These shapefiles are typically provided by TNRCC in a UTM projection as they are developed using the DRGs. The complete shapefile is projected to TSMS Albers.

Arc : **shapearc *sulwruutm01 sulwruutm01***
Arc : **project cover *sulwruutm01 sulwrualb01* utmtoalb.txt**
Arc : **copy *sulwrualb01 tmp1***
Arc : **arcshape *tmp1* point *tmp1***
Arc : **kill *tmp1* all**
ArcView : **In View menu "File," click on "Manage Data Sources"**
ArcView : **Rename *tmp1.shp* as *sulwrualb01.shp***

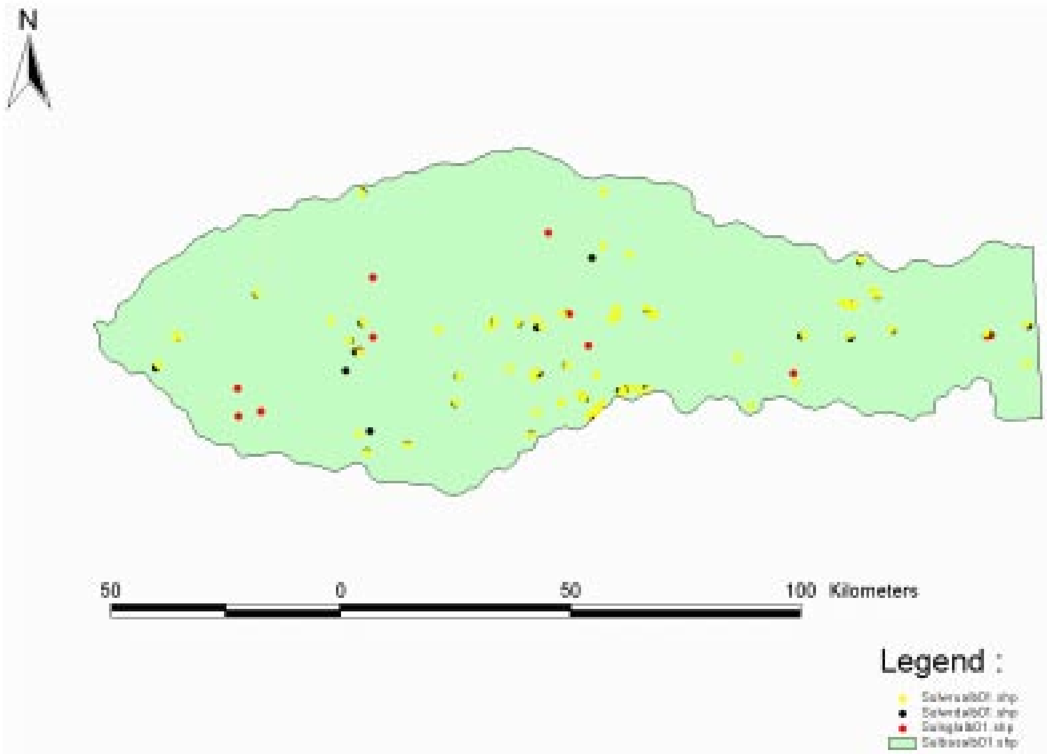


Figure 2.15 : Point Data Shapefiles in the Sulphur Basin

2.3.10 Curve Number Grid

The curve number grid is taken from a 1:250,000 scale curve number grid for the U.S. prepared at the Blacklands Research Center in Temple, Texas. This grid was produced by combining the USDA/NRCS STATSGO soil coverage with the USGS LULC coverage, both originally 1:250,000 map scale products. A lookup table was used to translate the combinations of soil and land use into curve numbers using the 1972 SCS Engineering Hydrology Handbook as a reference. The result was then transformed into a grid with curve number values sampled at a 250 meter interval. The original grid was projected to TSMS Albers and clipped to the extent of the Texas state boundary. A curve number grid for the basin, ***sulcngalb01*** is clipped from this grid, ***texcngalb***, to the extent of the buffered basin boundary. The cell size of the original grid is resized to match the cell size of the DEM.

Arc : **grid**
Grid : **mapex *sulbufalb01***
Grid : **setwindow *sulbufalb01***
Grid : ***tmpgrid1* = *texcngalb***
Grid : ***tmpgrid2*** = **selectpolygon(*tmpgrid1*, *sulbufalb01*, inside)**
Grid : ***sulcngtmp01* = resample(*tmpgrid2*, 84.993)**

The original Blacklands curve number grid contains NODATA values in open water bodies. An assumption is made for this project that areas corresponding to open water bodies are better represented by a curve number of 100, indicating complete translation of rainfall to streamflow. The grid is changed to fit this assumption.

Grid : ***sulcngalb01* = con (isnull(*sulcngtmp01*),100,*sulcngtmp01*)**
Grid : **quit**
Arc : **kill *sulcngtmp01* all**
Arc : **kill *tmpgrid1* all**
Arc : **kill *tmpgrid2* all**

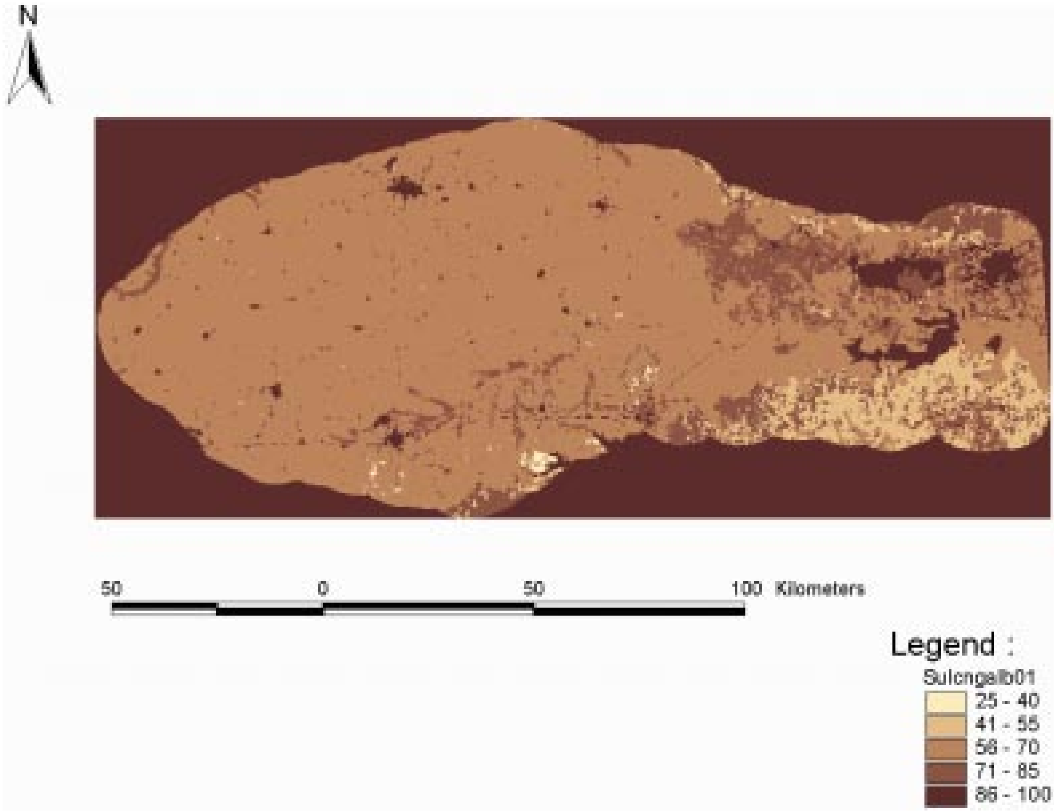


Figure 2.16 : Curve Number Grid of the Sulphur Basin

2.3.11 Precipitation Grid

The precipitation grid is taken from the USDA NRCS PRISM Climate Mapping Project. The PRISM (Parameter-elevation Regressions on Independent Slopes Model) model was developed to derive gridded estimates of climate parameters from point sources of data, considered in context with the terrain shown by a DEM. PRISM is an expert system that mimics the process a climatologist would use to map climate parameters. The model has been applied across the U.S., and the results have been reviewed and approved by the NRCS, a panel of state climatologists, and independent experts. The grid of annual average precipitation used here was based on analysis of monthly precipitation data from 1961-1990.

The original grid was downloaded from the PRISM internet site at http://www.ocs.orst.edu/prism/prism_new.html. The annual mean precipitation map of the Central US was downloaded. It was projected to TSMS Albers and clipped to the extent of the Texas state boundary.

The basin map, ***sulpcpalb01*** is clipped from this grid, ***texpcpalb***, to the extent of the buffered basin boundary. The cell size of the original grid is resized to match the cell size of the DEM.

Arc : **grid**
Grid : **mapex *sulbufalb01***
Grid : **setwindow *sulbufalb01***
Grid : ***tmpgrid1* = *texpcpalb***
Grid : ***tmpgrid2*** = **selectpolygon(*tmpgrid1*, *sulbufalb01*, inside)**
Grid : ***sulpcpalb01* = resample(*tmpgrid2*, 84.993)**
Grid : **quit**
Arc : **kill *tmpgrid1* all**
Arc : **kill *tmpgrid2* all**

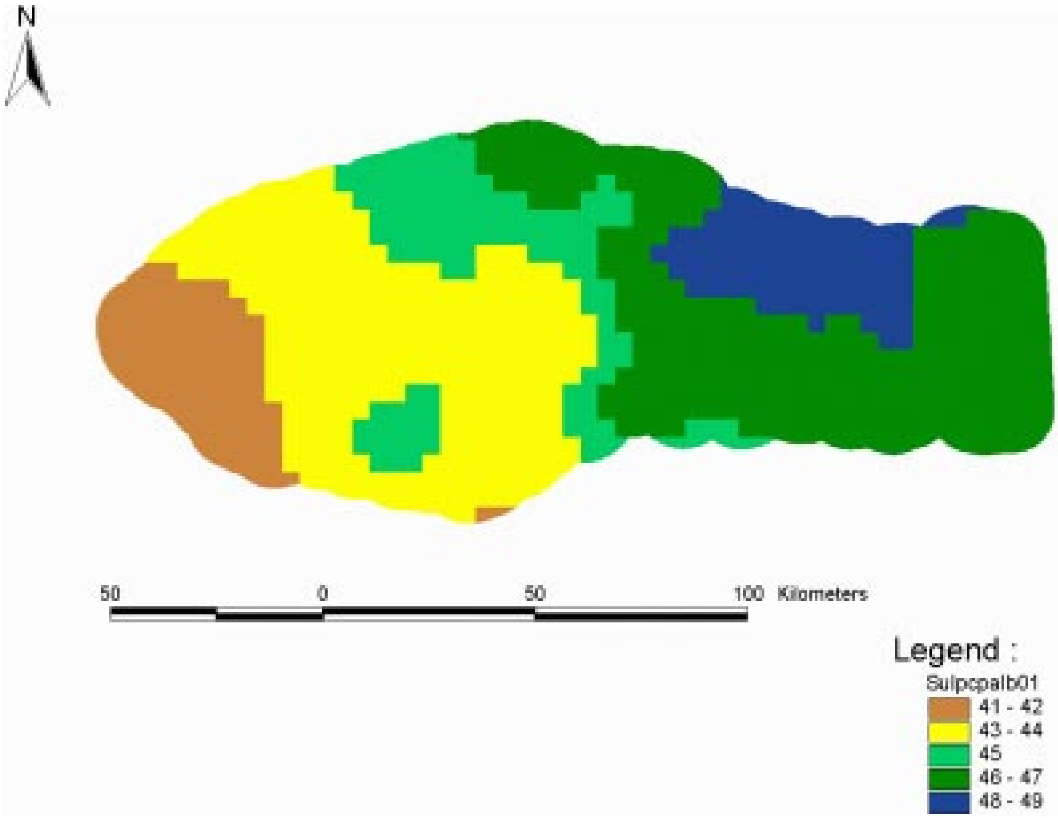


Figure 2.17 : Mean Annual Precipitation Grid (in./yr.) of the Sulphur Basin

2.3.12 Water Quality Segments

Coverages of TNRCC designated stream segments and segment boundaries were obtained from the TNRCC GIS base map internet site at http://www.tnrcc.state.tx.us/gis/base.html. These coverages were projected into the TSMS Albers projections and saved as ***texwqsalb*** and ***texwqbalb*** respectively. The coverages are clipped with the basin boundary producing a shapefile for each: ***sulwqsalb01.shp*** for the stream segments, and ***sulwqbalb01.shp*** for the segment boundaries. These shapefiles are not used further in this case study. For most river basins, TNRCC asks that the segment boundaries be included as control points, for future use in considering water quality impacts. They were not included in the original Sulphur basin model, as it was the first study of the project.

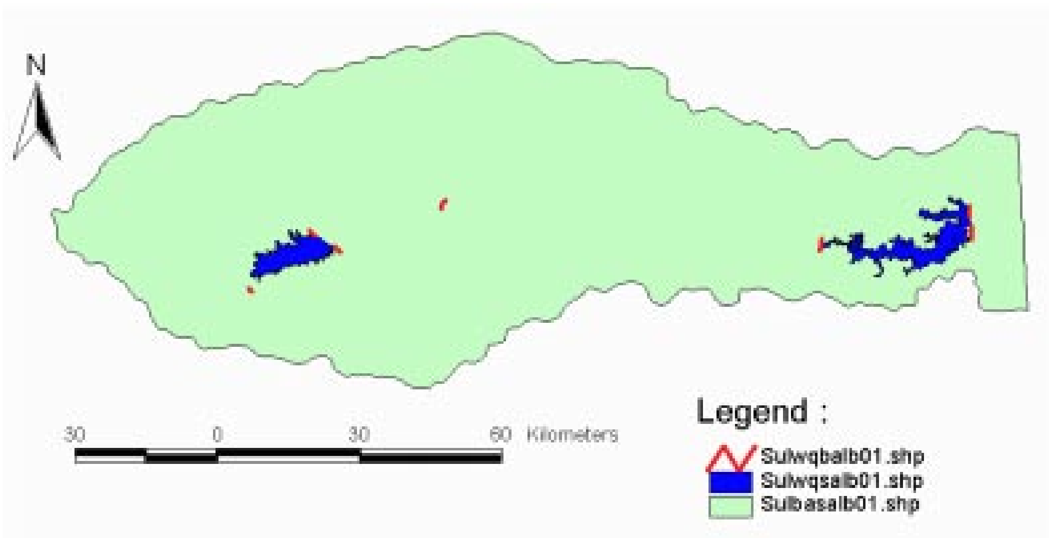


Figure 2.18 : Water Quality Segments and Boundaries

Chapter 3 : Methodology

3.1 PROJECT MANAGEMENT

The WAM Project is a complex task requiring the efforts of several agencies and engineering firms. Each basin is modeled by one or more contractors. To prepare the WRAP input parameters, it is necessary to interact with both TNRCC and the engineering firm preparing the basin model. Several tasks are involved in creating the geospatial database. CRWR, TNRCC, and the basin contractor each have responsibility for one or more of these tasks. In order to streamline and schedule this effort, a standard basin procedure has been developed at CRWR (CRWR, 1999). In this procedure, all the required tasks are listed in outline form as shown below :

1) Preliminary Database Compilation (CRWR)
   a) A preliminary database is compiled consisting of :
      i) A basin boundary defined by TNRCC’s river basin coverage of Texas
      ii) A 1:250,000 scale Digital Elevation Model from the USGS
      iii) A single line river network fromed by taking the single line reaches of the EPA River Reach File 3 for the basin, merging them with separately developed centerlines for lakes and large rivers produced by the USGS
      iv) A coverage of water right permit locations supplied by TNRCC
      v) A complete map base of Digital Raster Graphic (DRG) versions of the 1:24,000 USGS topographic maps for the basin
   b) The compilation of the single line network is labor intensive because the network has to be manually edited to ensure that it has no gaps and in some areas new centerlines have to be digitized where comparison of the USGS centerlines and the DRG's shows that to be necessary.
   c) This database is stored on CD-ROM's for each basin, one copy of which is supplied to TNRCC. The large size of the files for the DRG's means that several CD's are usually needed (2 for the Guadalupe, 4 for the Nueces, for example).

2) Data Checking and Editing (TNRCC)
   a) The database produced in step (1) is checked by TNRCC, as follows:
      i) Check the location of each water right on the DRG against the paper copy of the location map in the water right permit file. Move to a new location if necessary
      ii) Digitize new points for locations of each point of diversion
      iii) Assign each location a unique identification number, based on the following scheme : BBTWWWWWW.DDD, where
         (1) BB = basin number (01 to 23)
         (2) T = type of right (1 or 6)
         (3) WWWWWW = water right number (e.g. 05467)
         (4) DDD = diversion point number (1 to 50, or 51=offchannel reservoir)
      iv) Digitize additional tributary streams from the DRG's to connect water rights not presently on the river network to that network
      v) Supply shapefiles for the revised water right locations and stream segments to CRWR

3) Control Point Determination (WAM Contractor)
   a) The Water Availability Modeling Contractor for each basin determines the number of control points to be used. These control points are of two types:
      i) *Known flow* (primary) control points (e.g. stream gage locations)
      ii) *Unknown flow* (secondary) control points (water right locations and other locations of interest)
   b) The geospatial data produced by CRWR is used to apportion the flow at unknown flow control points on the basis of that at known flow control points.
   c) Based on their study of the basin, the contractor supplies to CRWR:
      i) A list of the stream gages and their locations to be used as known flow control points
      ii) A list of unknown flow control points which are also water right locations, in other words, those locations taken from TNRCC's complete list of water right diversion points, which are actually going to used as control points in the WAM analysis for the basin
      iii) A list of additional control points (both known and unknown flow). For each point on this list, a copy of a paper map location is supplied so that the digital location of the control point can be verified.

4) Watershed Parameter Development (CRWR)
   a) CRWR develops the control point watersheds and parameters for the basin and provides this data to the contractor. CRWR provides a spreadsheet with the tabulated parameters, and ArcView shapefiles of the control point, stream network, and watershed themes used to develop the parameters. Specifically, the following parameters are supplied :
      i) Incremental watershed area
      ii) Total watershed area
      iii) Mean precipitation in the total watershed area
      iv) Mean curve number in the total watershed area
      v) ID of the next downstream control point
      vi) ID of the next downstream known flow (primary) control point

5) Basin Products (CRWR)
   a) CRWR produces a CD-ROM with the following products :
      i) GIS coverages of the basin in both TSMS and TSMS Albers map projections
      ii) Metadata for the basic GIS coverages
      iii) A basin-specific quality assurance report
      iv) Watershed parameters
      v) A set of ArcView procedures for the use and update of the database
      vi) Documentation for the use of the ArcView procedures
   b) This CD-ROM is distributed to TNRCC and the contractor. If the contractor would like training in the use of the ArcView procedures for the database use, CRWR supplies training on an informal basis.

6) TNRCC Approval (TNRCC). TNRCC reviews the final database. Upon TNRCCs approval, CRWR stops updating control points and watershed parameters in the basin.

The rest of this chapter focuses on the methodology used to accomplish step four of this process, the watershed parameter development. Section 3.2 first briefly discusses steps one and two, and Section 3.3 discusses step three of the procedure.

3.2 BUILDING A WATER RIGHTS LOCATION REVIEW DATABASE

The Water Rights Location Review Database is the preliminary database referred to in step one of the project management procedures. It is a tool designed to aid TNRCC staff in locating the diversion and return flow points associated with each water right permit. This work is described in step two, “Data Checking and Editing,” of the project management procedures. By digitizing these points as they are identified, TNRCC can then easily provide them to CRWR and contractors for use in locating model control points. The following files are written to a CD-ROM :

- ***texmesutm15.shp***
- ***sulbasutm01.shp***
- ***sulrfiutm01.shp***
- ***sulsglutm01.shp***
- ***sulwrdutm01.shp***
- **uniques.dbf**
- **wrap.apr**
- **DRG TIFF image files**

Depending on the number of DRGs required to cover the basin, they may need to be split among several CDs. Each CD should include the basic shapefiles above. The DRG database is also used extensively in the stream network editing described in Section 3.5 and in the quality control process described in Section 3.12.

3.3 ESTABLISHING THE MODEL CONTROL POINT LOCATIONS

Control points represent any location in the model where flows are simulated. Control points are used to represent primary, or known flow, and secondary, or unknown flow, control points. Primary control points are usually stream gages, but may be any point where a record of naturalized streamflows is developed. Secondary control points typically represent water right diversion points, so that the reliability of the monthly flow to supply the diversion demand can be estimated. Control points may be inserted for a variety of other reasons. For example, they may be used at a point where return flows are made to a stream or to determine the regulated flow available in a water quality segment.

The contractor who builds and operates the basin model ultimately decides where the control points will be located. CRWR provides some raw data useful in establishing control point locations: the basin stream gage shapefile, ***sulsglalb01.shp***, and the water rights database shapefile, ***sulwrdalb01.shp***. TNRCC develops a shapefile showing each diversion point for every water right in the basin, ***sulwruutm01.shp***. Once the contractor has decided on the control points, these locations must be exactly reproduced as a GIS coverage in order to correctly determine the flow distribution parameters at each point.

For control points that are part of the basic shapefiles already produced (stream gages and water right diversion points), translating the contractor's choice of control points to a shapefile is easily done. The contractor just supplies CRWR with a list of which points to use. Points not in these original coverages can be more challenging. Contractors will develop primary control points at locations other than stream gages and they may have many other secondary control points. For example, a water right with several diversion points located very near each other may be modeled with a single secondary control point just downstream of all the diversion points.

Experience with the project so far has shown a topographic map to be the most unambiguous means of communicating control point locations. Simply providing a latitude/longitude coordinate for these points is often not clear enough. For a point on an isolated or major stream channel this may be fine. For points that are located near junctions or near multiple tributaries, however, even with a coordinate and descriptive information, the correct location of the point on the stream network may be confusing. A map sheet with the control point marked can be faxed or sent electronically. The point can then be correctly located in ArcView using the DRG files as a common reference. Figure 3.1 shows a map section supplied by the contractor locating two control points in the Sulphur basin.

Control points are actually entered using the “Add Control Point” tool. Before using this tool the name of the control point theme must be set using the WRAP Tools menu item “Set Control Point Theme Names.” Control point identifiers must be integers, and may be up to twelve digits in length.

Eighty-two control points were used in the WRAP model of the Sulphur basin. Six of these represented off-channel reservoirs for which the contractor chose not to use the GIS flow distribution parameters. Therefore, seventy-six control points were used in this study. The Sulphur Basin model was completed before the standard water right numbering system proposed in section 3.1 was developed. The contractor decided to split the basin into six sub-watersheds, labelled A to F, and number the control points within these sub-watersheds. The WRAP Parameters interface code requires that control point identifiers be entered

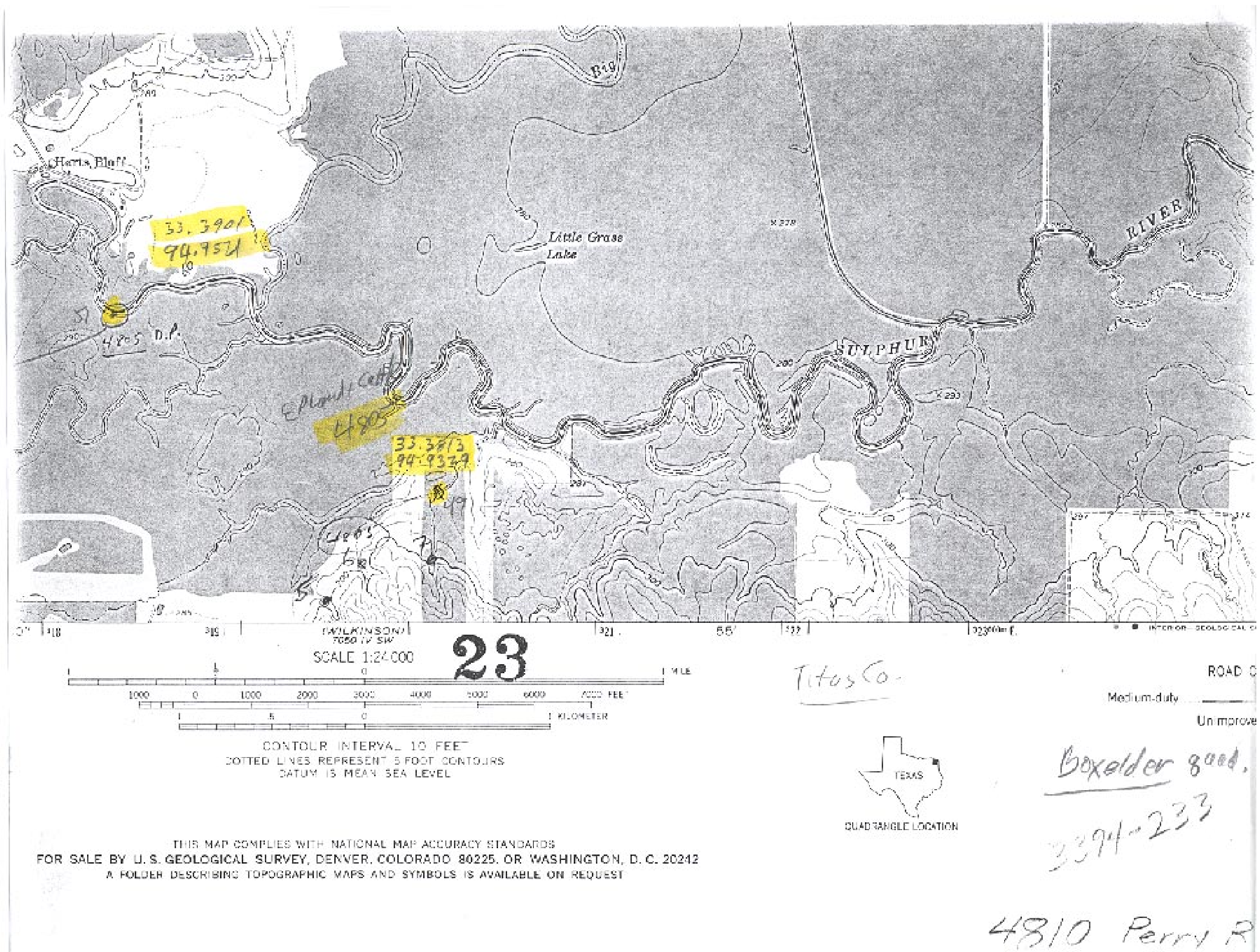


Figure 3.1 : Contractor Supplied Control Point Map

as integers The numbers 1 to 6 were used to represent the sub-watersheds, F to A, respectively. The sub-watershed number is then followed by the control point number. The control point ID 1010 in ***sulfcpalb01.shp***, for example, is used for the model control point F10.

3.4 EDITING THE STREAM NETWORK

The goal of the stream network editing is to produce a digital representation of mapped hydrography that will be used to define a channel network within the digital elevation model. In developing the stream network, an original coverage of digitized mapped hydrography, in this case RF3, is edited to fit the project definition of a stream network : oriented single-line reaches, each connecting to only one downstream reach. Digital topographic maps are then used as a reference to add features, such as smaller tributaries, to the stream network, and to resolve conflicts between the RF3 mapped hydrography and the single-line network representation. While RF3 is originally a 1:100,000 map scale product, it is observed to fit very closely with the DRG hydrography, which is at 1:24,000 scale.

In this project, the vector stream network is used as a tool to modify the DEM to better reflect mapped hydrography. When editing the stream network, familiarity with defining streams from a DEM is helpful. The vector stream network is used to condition the DEM so that the raster streams defined from the DEM will correspond to the vector streams. As the stream network is being edited, some intuition as to how the DEM will reproduce the vector stream network will help in resolving some conflicts. Through the flow direction algorithm, the DEM will define a gridded stream network equivalent to a single-line vector network, but at the map scale of the DEM data. In this work, a 1:100,000 scale vector stream network is edited with 1:24,000 scale hydrography A 1:250,000 scale DEM cannot exactly replicate features defined at these larger map scales. In places where multiple stream network arcs are located within a distance of the grid cell size of the DEM of each other, the raster stream will take only one path (one grid cell). In general, a coarse resolution DEM will partially negate the details of finer resolution vector stream networks. Hydrologic modeling with DEMs is discussed in more detail in Section 3.6.

Once all edits have been made to the working versions of the stream networks, they should be saved as final versions, ***sulsfvutm01.shp*** for the interior and ***sulsfxutm01.shp*** for the exterior. These shapefiles are projected to the TSMS Albers system.

Arc : **shapearc *sulsfvutm01 sulsfvutm01***
Arc : **shapearc *sulsfxutm01 sulsfxutm01***
Arc : **project cover *sulsfvutm01 sulsfvalb01* utmtoalb.txt**
Arc : **project cover *sulsfxutm01 sulsfxalb01* utmtoalb.txt**
Arc : **build *sulsfvalb01* line**
Arc : **build *sulsfxalb01* line**
Arc : **copy *sulsfvalb01 tmp1***
Arc : **copy *sulsfxalb01 tmp2***
Arc : **dropitem *tmp1.aat tmp1.aat***
Enter the 1st item : **fnode_**
Enter the 2nd item : **tnode_**
Enter the 3rd item : **lpoly_**
Enter the 4th item : **rpoly_**
Enter the 5th item : **end**
Arc : **dropitem *tmp2.aat tmp2.aat***
Enter the 1st item : **fnode_**
Enter the 2nd item : **tnode_**

Enter the 3rd item : **lpoly_**
Enter the 4th item : **rpoly_**
Enter the 5th item : **end**
Arc : **arcshape *tmp1* line *tmp1***
Arc : **arcshape *tmp2* line *tmp2***
Arc : **kill *tmp1* all**
Arc : **kill *tmp2* all**
ArcView : **In View menu, "File," click on "Manage Data Sources"**
ArcView : **Rename *tmp1.shp* as *sulsfvalb01.shp***
ArcView : **Rename *tmp2.shp* as *sulsfxalb01.shp***

Many unique situations are encountered when editing the stream networks of different basins. While there are no absolute rules for how to manage these situations, there are three principles which should be consistently adhered to:

1. build a single-line network
2. in the vicinity of a control point, add all surrounding streams
3. maintain correct arc-node topology in the coverage

The DRGs are used as a reference in accomplishing the first two of these tasks, and correct topology is maintained with ArcView and WRAP Parameters tools. The external stream network, ***sulswxutm01.shp***, is only used to condition the DEM. Streams are added to the theme in the vicinity of control points, but it is not necessary that it be built as a single line network, nor must its topology be correctly maintained.

3.4.1 Build a Single-Line Network

Real channel networks do not always follow a single downstream flow path and RF3 captures these real channel features. Open water features are removed from the stream network when RF3 is queried for true reaches, but the base stream network still has some unconnected arcs and braided rivers.

Unconnected arcs may occur due to errors in the RF3 “Reachtype” attribute classification or they may be the result of digitizing errors in the original RF3 development. If the segment can be identified from the DRGs as actually belonging to a stream, it can be connected to the stream network. Otherwise the segment is deleted.

Braided streams are defined as “a number of alluvial channels with bars or islands between meeting and dividing again, and presenting from the air the intertwining effect of a braid” (Lane, 1957). Braided channels are reduced to one single-line reach through the entire braided channel system. Channel paths in a braided river depend on many factors, such as channel stage, and vary over time. For this work, it is not important to accurately define one major channel through the system. The editor should examine the DRG and use his or her best judgement. Arcs connecting inflowing tributaries should be kept to maintain the stream network connectivity. Similarly, large sloughs (dead channels) are removed.

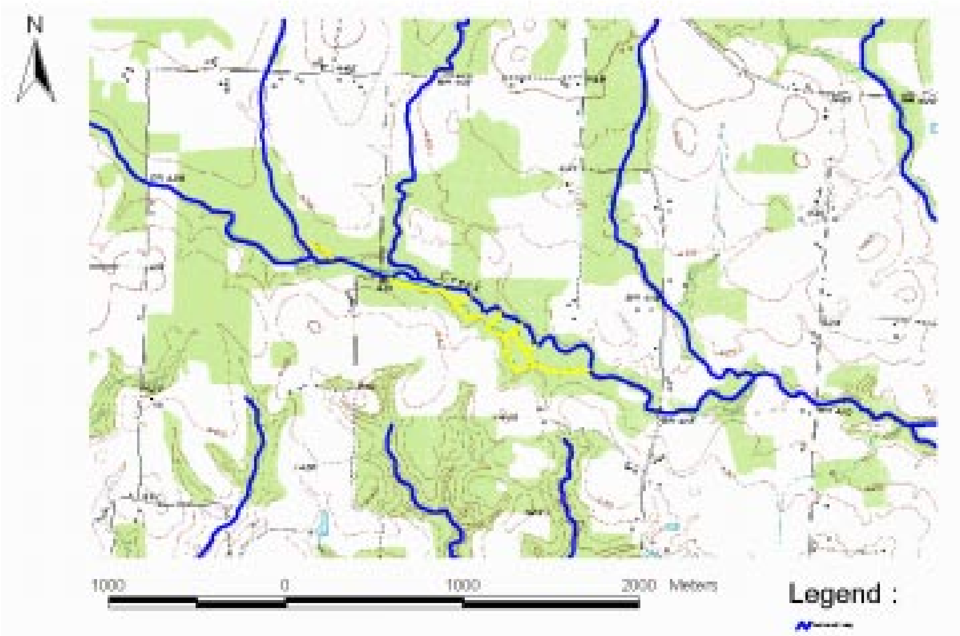


Figure 3.2 : Braided Channel (highlighted arcs are deleted)

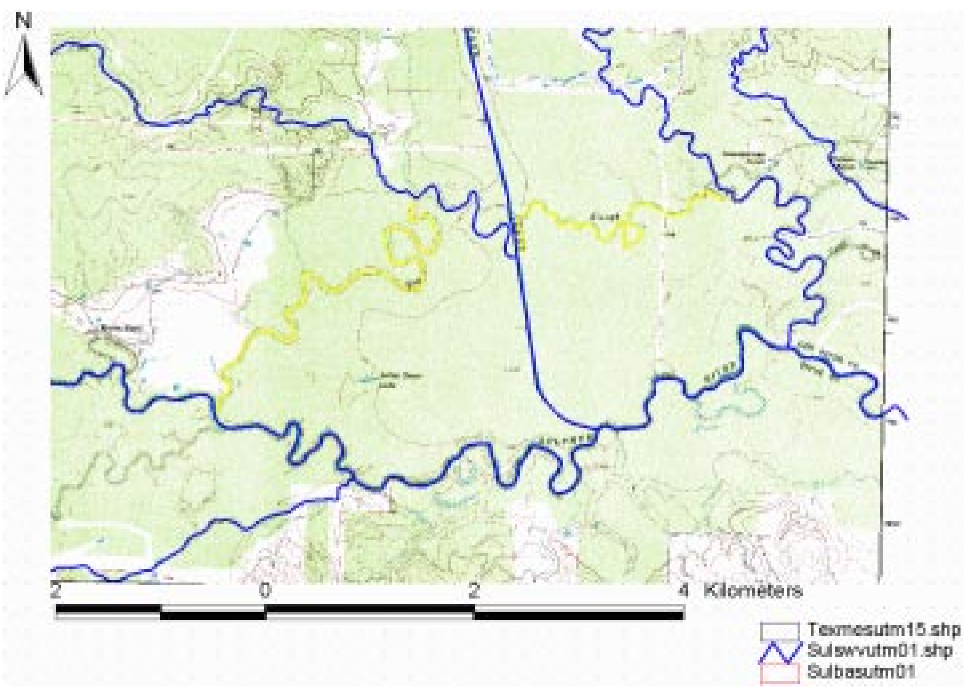


Figure 3.3 : “Big Slough” Channel (deleted) on Sulphur River

A river basin may contain many small braids. Over the course of editing an entire river basin it is quite possible that some of these will be missed. It is not critical that they all be removed. The raster stream network defined by the DEM will simply choose a path between the two. Over a short distance, this will not have any adverse effects on drainage area determination.

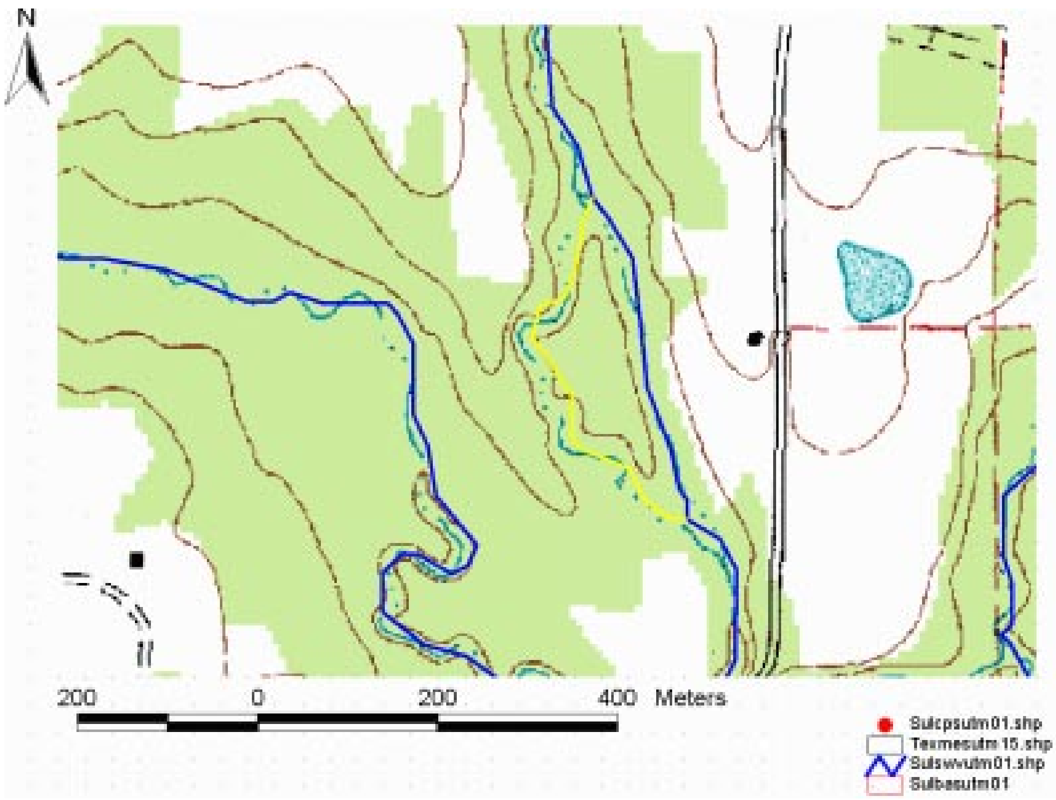


Figure 3.4 : Small braid (highlighted arc is deleted)

One type of channel braiding, “anastomosing,” may present problems for the methodology in this project. Anastomosing channels are defined by “longer than a curved channel segment around a single braid or point bar and their width-scale flow patterns behave substantially independently of adjacent segments" (Bridge, 1993). Figure 3.5 illustrates this definition of anastomosing channels. If a control point is located on one branch of an anastomosing channel, the drainage area could be determined by splitting the arc of the other branch at the divergence point. The split arc would not accumulate any flow from upstream of the divergence. However, in the WRAP model, the total flow for both branches would then be distributed to this control point, where in reality the flow is split between the two branches. In this case, the flow distribution to this point will have to be specifically modified by the contractor running the model.

Other situations, unique to each basin, will present themselves. They must be resolved as best possible. In the Sulphur basin, two RF3 reaches were found which appeared to laterally connect two parallel channels. In both of these cases, inspection of the DRGs showed that the digitized reaches actually crossed over levees shown on the topographic map. In these cases, the arcs were either split at the levee, or deleted altogether. Figure 3.6 shows an RF3 reach near the confluence of the North and South Sulphur Rivers. The reach, as digitized in RF3 actually crossed over the levee shown on the DRG. The reach was deleted. Note that the levee will not be represented in the DEM, which samples elevations at approximately every 90 meters. It would not be appropriate, however, to retain the deleted channel. In this case, the DEM terrain will determine the drainage pattern of the area within the levee.

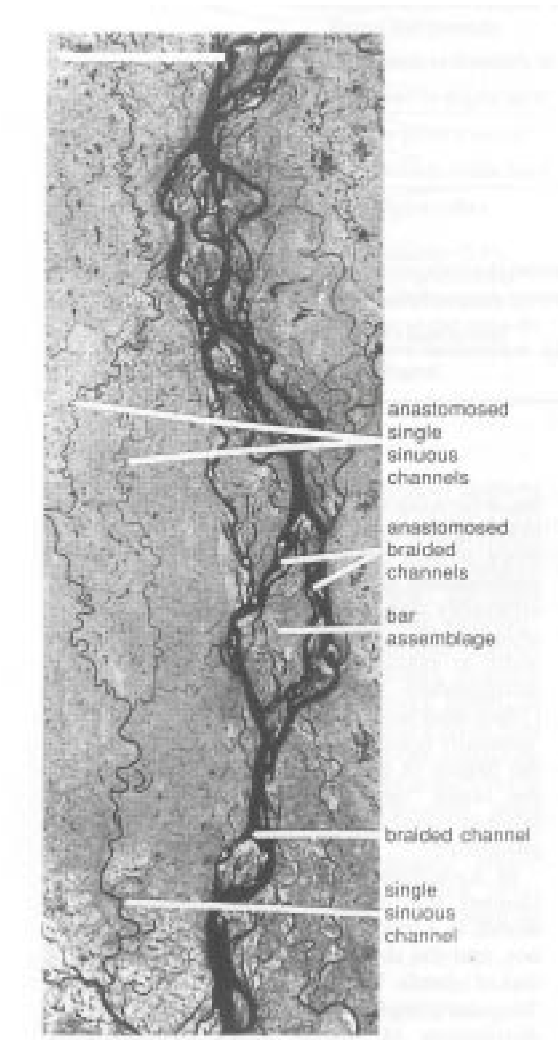


Figure 3.5 : Anastomosing Stream Channels (Bridge, 1993)

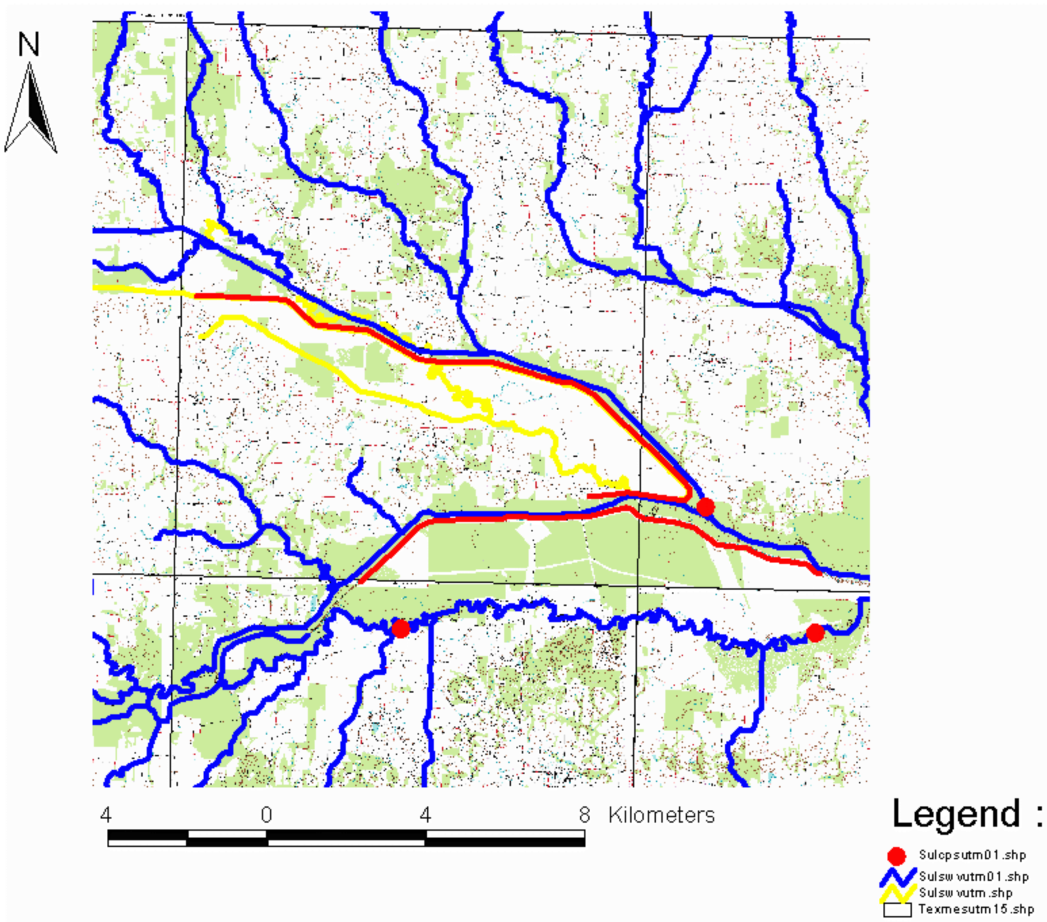


Figure 3.6 : Levee System (in Red) at Fork of North and South Sulphur Rivers

3.4.2 Adding Streams

It is important to add all the streams surrounding a control point. The stream network is used to condition the DEM to reflect the hydrography shown in the topographic map. Without this conditioning, the drainage area defined by a small scale DEM, in this case 1:250,000, may be significantly different than what would normally be delineated from the topographic map. The drainage areas may be over or under-estimated. Figure 3.7 shows the original RF3 in blue and streams that were identified from the DRG and added (in yellow) in the vicinity of one control point in the Sulphur basin. Figure 3.8 shows a case of over-estimated drainage area. Figure 3.9 shows a case of under-estimated drainage area. In both of these figures, the original RF3 streams and the watershed boundary delineated from a DEM burned with just the RF3 streams are shown in red. The correct drainage area, and the streams added to the RF3 to help define the correct drainage area, are shown blue.

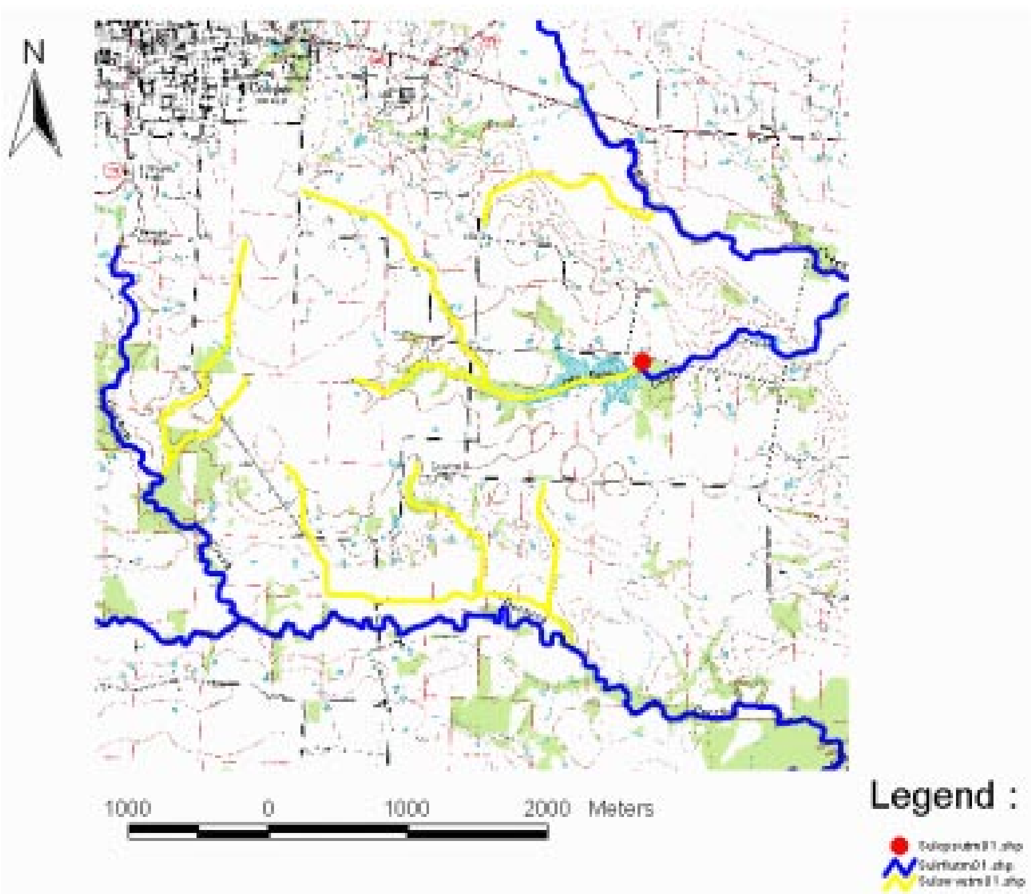


Figure 3.7 : Streams Added (highlighted) to the Base Network

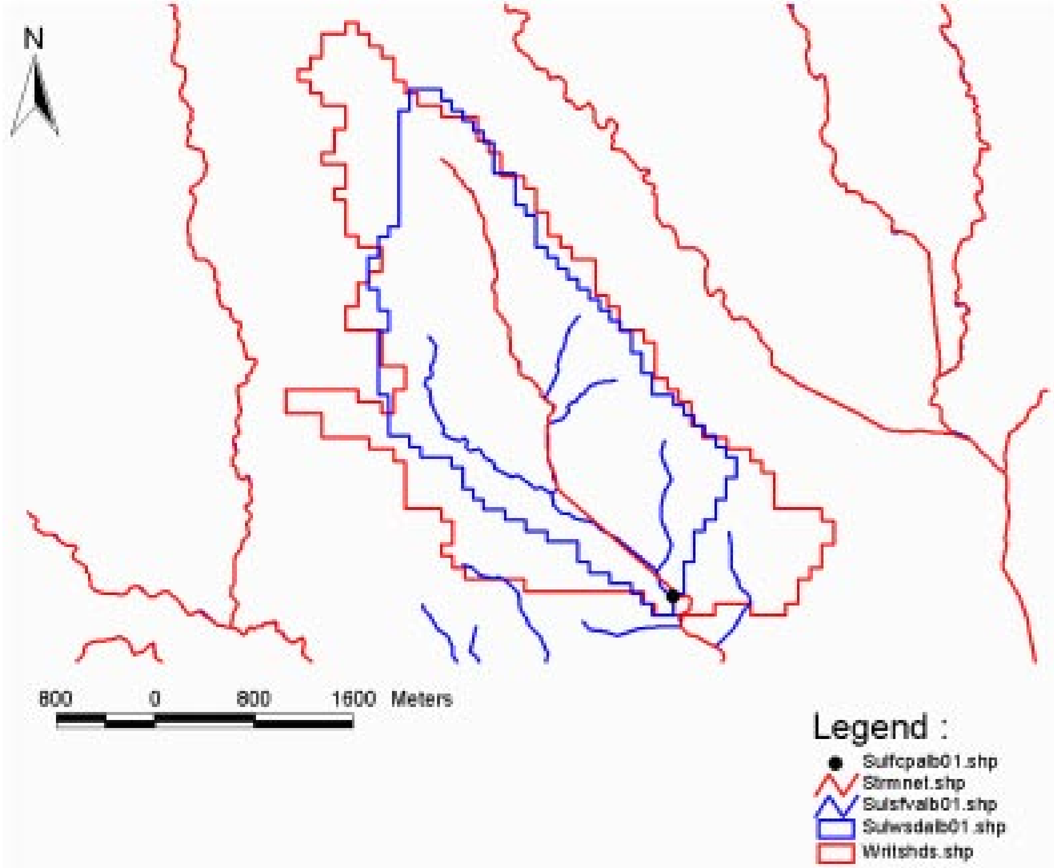


Figure 3.8 : Over-estimated Drainage Area

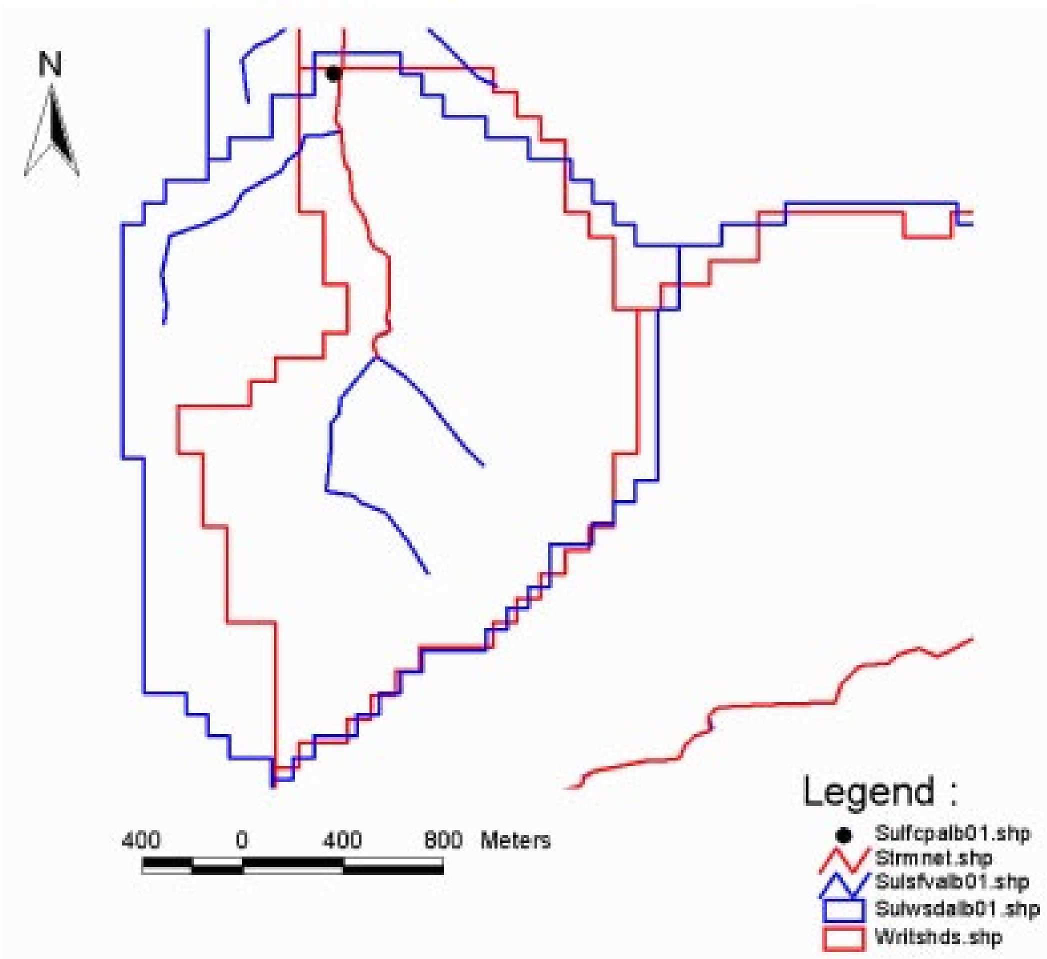


Figure 3.9 : Under-estimated Drainage Area

For control points located along the basin boundary, drainage areas will also be defined by the streams exterior to the basin boundary. In the vicinity of these control points, exterior streams should also be added to ***sulswxutm01.shp***.

3.4.3 Correcting Arc Topology

Arcs are defined by a set of points called vertices. The two endpoints of an arc are the nodes. Arcs are oriented in the direction of the from-node to the to-node.

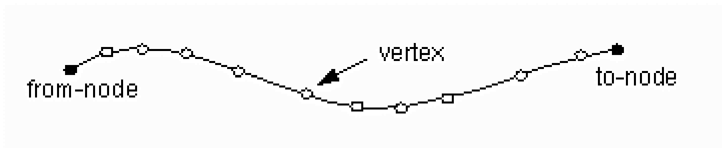


Figure 3.10 : Arc Definition

A line coverage is said to have correct arc-node topology when all the arcs are arranged in a manner such that the connecting arcs share nodes. There are three types of nodes : normal, pseudo, and dangling. Normal nodes are those which connect the endpoints of more than two arcs. Pseudo nodes connect the end of one arc to the beginning of another. Dangling nodes are endpoints that do not intersect any other node. Figure 3.11 illustrates the three types of nodes. In ArcView, line themes are composed of polylines. Polylines have the same properties as arcs. The term “arc” is used throughout this chapter and should be understood to mean arcs in an ArcInfo coverage or polylines in an ArcView theme.

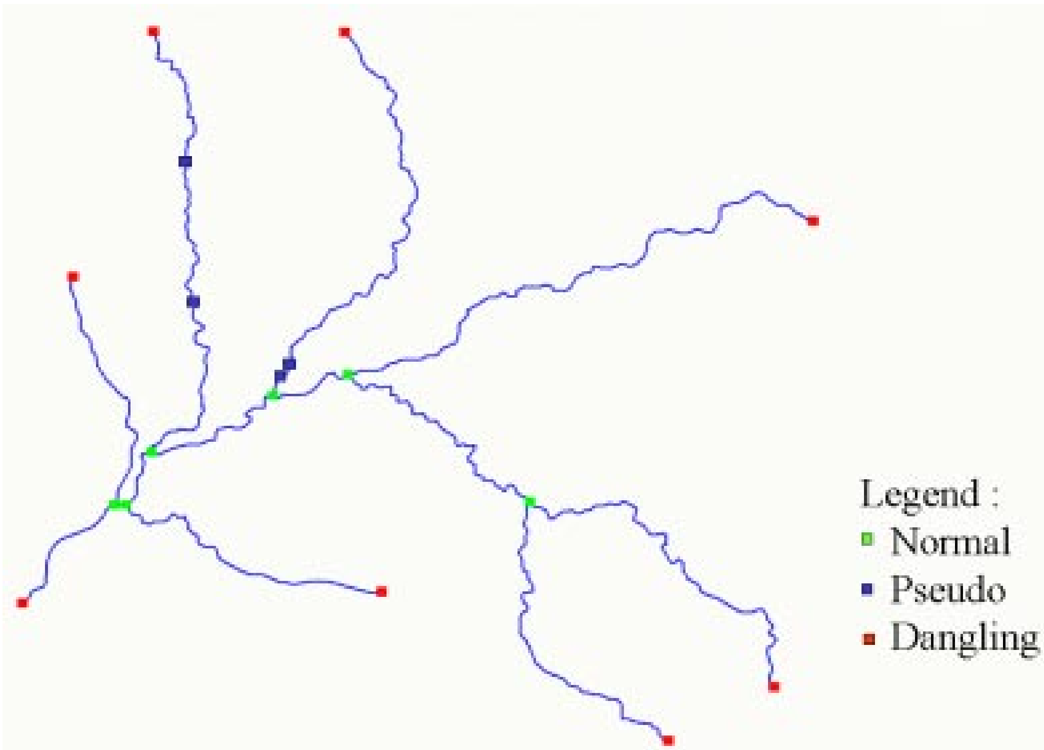


Figure 3.11 : Node Definition

One error in the stream network topology comes from merging the USGS centerline shapefile, ***sulctlutm01.shp***, with the RF3 theme, ***sulrfiutm01***. The endpoints of these two themes do not exactly match, introducing small disconnects into the network. These may be corrected by using the "Vertex Editor" tool to move one node onto the other. Figure 3.12 shows the corrected final stream network (in green) overlaid on two disconnected arcs. Before moving a vertex, the snapping tolerance of the theme should be set to the scale of the disconnect area

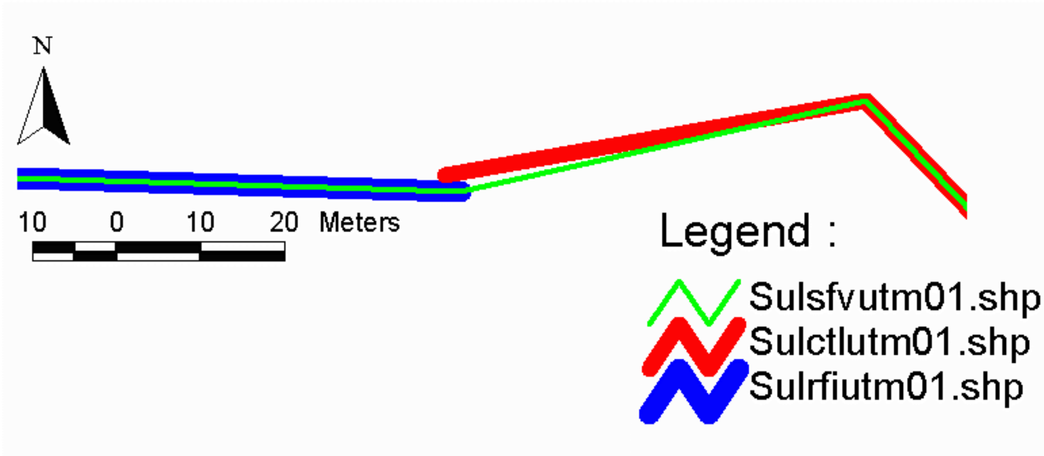


Figure 3.12 : Disconnected Arcs Corrected with “Vertex Editor” Tool.

Another problem arises as the stream network is being edited. As tributaries are added, the endpoint of the added tributary is snapped to an existing stream. The endpoint of an arc snapped to the middle of another arc is a dangling node, however, since it is not actually connected to any other node in the theme. This is shown in Figure 3.13. In this project these points are called interior dangling nodes. This problem can be corrected by splitting the original stream arc at the point where the new tributary intersects it, creating three arcs : the tributary arc, an arc upstream of the tributary intersection, and an arc downstream of the tributary intersection. The node at this point is now recognized as a normal node, since three arc endpoints connect there. The “Erase Interior Dangling Nodes” tool makes this correction.

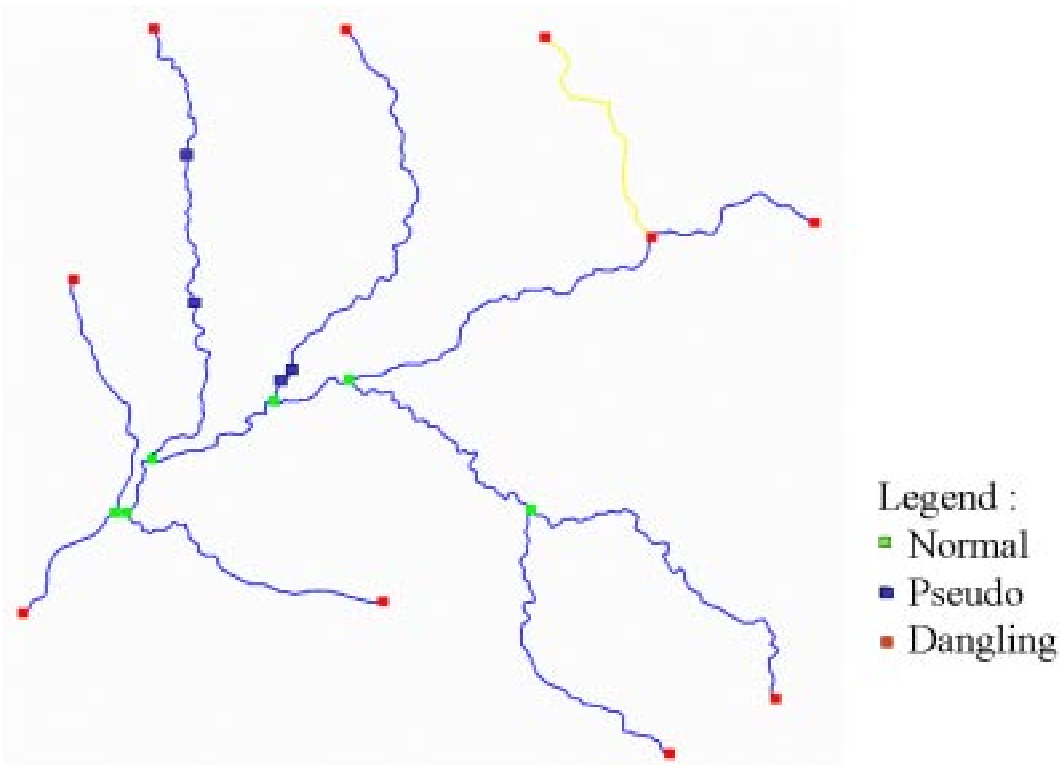


Figure 3.13 : Interior Dangling Node at End of Added Arc (Highlighted)

Some interior dangling nodes may be the result of overlapping arcs. This often occurs when using the interactive snapping features within a wide tolerance. If the “Erase Interior Dangling Nodes” tool fails to correct the interior dangling node, zoom in on the display and check for overlapping arcs. In some cases it may be necessary to check the theme attribute table to see if multiple arcs are selected for what appears graphically to be a single arc. Overlapping arcs can be corrected using either the “Vertex Editor” or “Split Lines” tools.

Two overlapping arcs connected at a headwater endpoint will cause the headwater not to appear as a dangling node. It is actually a pseudo node. In this case it is hard to select one of the arcs graphically, as they often exactly overly each other. This can be overcome by deleting one of the arc records from the attribute table.

Coverage topology can be automatically fixed in ArcInfo with the “clean” command. This is a complex process, however, and it should be completely understood before applying it to the stream network. In particular, “clean” works within a specified tolerance. The command specifications for clean are :

Arc : **clean <in_cover> {out_cover} {dangle_length} {fuzzy_tolerance} {POLY|LINE}**

The fuzzy tolerance is the minimum allowable distance between any two vertices in the coverage. Any vertices within a radius of the fuzzy tolerance will be combined into a single vertex. To correct disconnects in the base stream network for example, the fuzzy tolerance would have to be set at a radius greater than the largest distance of the disconnects. In very sinuous stream arcs, or where stream arcs approach one another, regular vertices in the arcs may be located within the fuzzy tolerance. At a certain raidus, vertices in the stream network arcs will begin being modified. There is no easy way of determining what tolerance value will correct mistakes in the topology while not affecting regular vertices. To avoid unwanted modifications to the stream network, this project puts an emphasis on correcting the coverage topology without using “clean," using the combination of existing ArcView tools and specialized scripts described above.

3.5 HYDROLOGIC MODELING USING DIGITAL ELEVATION DATA

Hydrologic modeling with GIS is based on the automated delineation of watersheds from DEMs. The key concept in carrying out drainage area analysis with a DEM is the eight direction pour point model. A pour point is a location through which water flows out of a region, in this case a DEM cell. A given grid cell is surrounded by eight neighboring cells. Water in this cell is modeled as flowing into only one of the neighboring cells, in the direction of steepest descent. The flow direction for each cell is coded with an integer value, as shown in Figure 3.14.

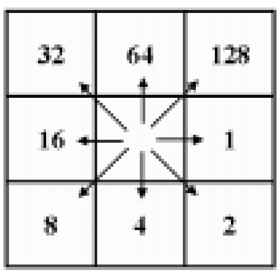


Figure 3.14 : Eight Direction Pour Point Model

The grid resulting from applying this analysis to all cells in the DEM is called the flow direction grid. From this grid the flow accumulation of each cell can be determined. The flow accumulation grid shows, for each cell, the number of upstream cells draining to that cell. Typically, streams are defined from a DEM at a threshold value of the flow accumulation. Any cell with a flow accumulation value equal or greater than the threshold is considered a stream cell. Drainage areas may then be defined for any point along the streams by backtracking along the flow direction grid. Figure 3.15 shows a watershed with flow direction and flow accumulation. In this example, stream cells, shown in blue, are defined by a threshold value of five cells.

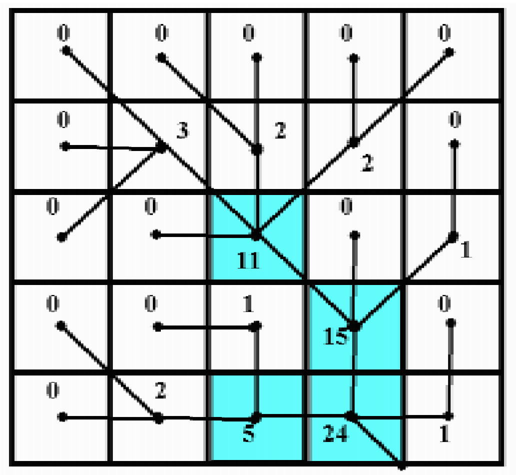


Figure 3.15 : Grid Showing Flow Direction, Flow Accumulation, and Stream Definition

At CRWR, a procedure has been developed to condition DEMs to more accurately reflect the drainage shown by vector stream networks. Without using this process, DEM defined streams may vary greatly from mapped streams, especially in areas of flat terrain such as the Texas coast. The process, called "burning" streams, effectively superimposes the stream network onto the DEM and digs a ditch into the DEM where the network lies. What is actually done is to convert the stream network to a grid with the elevations of the original DEM, and then to raise all the cells in the DEM by a constant (arbitrary, but typically chosen to be larger than the highest elevation value.) The stream network grid with the original elevation values is then merged into the raised DEM. In the subsequent flow direction analysis of the burned DEM, the flow will follow the relief of the original DEM until it enters the stream network, now with much lower elevation than the surrounding terrain. The flow will then stay in the burned stream network until it reaches the basin outlet.

Figure 3.16 illustrates the DEM burning concept. Conceptually, the burning process calibrates the DEM to the hydrography defined by the mapped stream network. DEMs by themselves are useful tools for automating drainage area delineation, but experience has shown that small scale DEMs should not be relied upon to produce accurate stream definition and drainage areas in flat terrain.

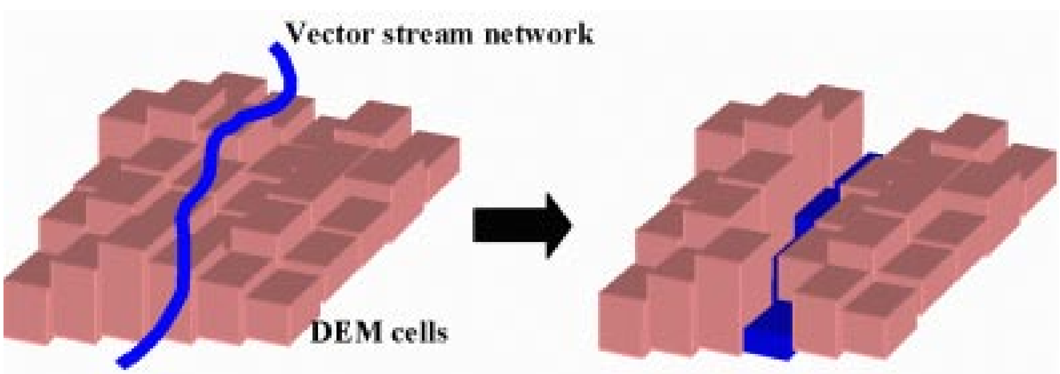


Figure 3.16 : Conceptual View of the Stream Burning Process

The WRAP Parameters menu item “Burn DEM” is used to burn the stream network into the DEM. The finalized stream network, ***sulsfvalb01.shp***, is first combined with the RF3 shapefile of HUCs external to the basin, ***sulsfxalb01.shp***.

ArcView : **In View menu "WRAP Tools," click on "Merge Themes"**
ArcView : **Select *sulsfvalb01.shp* and *sulrf3alb01.shp***
ArcView : **Set the output shapefile name to *sulsbnalb01.shp***

The merged shapefile, ***sulsbnalb01.shp***, is the line theme used to burn the DEM. The output grid is a temporary grid named ***burndem***. Before the theme ***burndem*** is deleted from the View, the grid must be copied to make it a permanent grid. Burning the streams surrounding the basin into the DEM helps to ensure accurate drainage area delineation near the basin boundary.

The menu item "Fill the DEM" is used to fill sinks in the burned DEM. The output grid is ***filldem***. "Flow Direction," and "Flow Accumulation" produce the flow direction grid, ***fdr***, and flow accumulation grid, ***fac***. These grids are also temporary and must be copied into permanent grids.

ArcView : **In View menu "File," click on "Manage Data Sources"**
ArcView : **Copy *burndem* to *sulbdmalb01***
ArcView : **Copy *filldem* to *sulfdmalb01***
ArcView : **Copy *fdr* to *sulfdralb01***
ArcView : **Copy *fac* to *sulfacalb01***

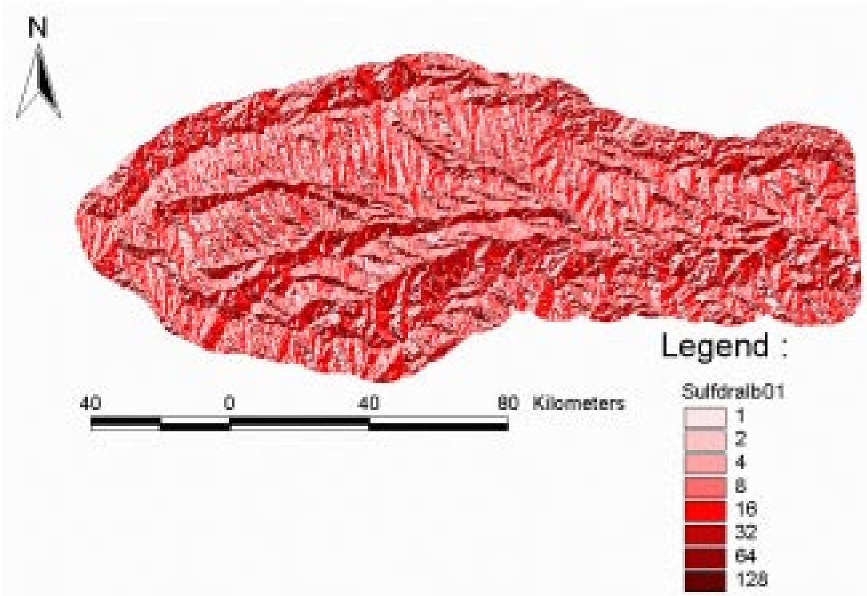


Figure 3.17 : Flow Direction Grid for Sulphur Basin

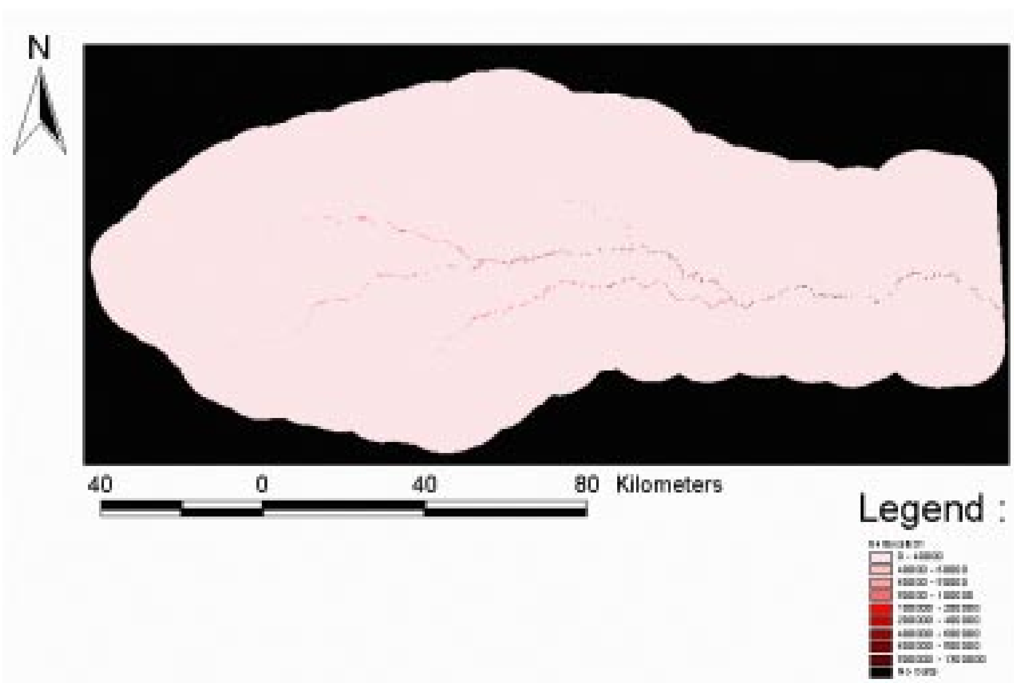


Figure 3.18 : Flow Accumulation Grid for Sulphur Basin

3.6 DEM DEFINED STREAM NETWORK

The normal approach to defining a DEM stream network is to apply a threshold value to the flow accumulation grid. This is the approach used in the original CRWR Prepro. This approach presented some problems when it was first applied in the WAM project. In order to correctly read control point parameters, the points must be placed on the DEM stream network. Many control points representing small water right diversions lie far upstream on the stream network. Typically a very small threshold value has to be applied to extend the DEM stream network to these locations. CRWR Prepro has a function, "Add Streams," to overcome this problem, but applying it to these points proved difficult, especially in large river basins where there are many of these control points.

For this project, a different approach to DEM stream definition was developed, avoiding this problem altogether. Recognizing that, in a stream network theme with correct topology, the dangling nodes represent the headwaters of the stream network, it is possible then to trace the flow direction grid from each dangling node of the stream network to the basin outlet. Each trace is output as a polyline, creating a line theme showing the DEM representation of the stream network. The WRAP Parameters menu item "Define Flow Direction Stream Network" does this. The output shapefile is ***fdrstrmnet.shp***. During execution, this script creates two shapefiles in the working directory, ***headwater.shp*** and ***centered.shp***. These are temporary shapefiles used to identify the headwater nodes and center them on the flow direction grid cells, and are deleted.

Each polyline in this line theme extends from a headwater to the basin outlet, creating a very large file with thousands of overlapping lines. These overlapping lines are split into individuals segments to conform to the stream network definition. This is easily done with the ArcInfo, “clean” command. In this case, by setting the fuzzy tolerance to a minimum, “clean” may be used without causing unwanted changes to the stream network arcs. Since the arcs in this theme are defined from the flow direction grid, no vertices will be closer than the grid cell size. Enter a very low tolerance, such as 0.001. This tolerance will then be defaulted to the minimum allowed by the coverage. “Clean” will now simply segment and remove overlapping arcs in the coverage without moving any nodes or vertices. If "clean" does modify arc positions and directions, these errors will be identified when the stream network connectivity is built.

Arc : **shapearc *fdrstrmnet temp***
Arc : **clean *temp temp* # 0.001 line**
Arc : **build *temp* line**
Arc : **arcshape *temp* line *temp***
Arc : **kill *temp* all**
ArcView : **In View menu “File,” click on “Manage Data Sources”**
ArcView : **Rename temp.shp as sulsdmalb01.shp**

A script has been developed that defines the flow direction stream network without overlapping lines. This script, “wrap.fdrstreams_mod,” has been successfully tested on small example stream networks, but was found to be too slow when applied to a large river basin. It is included in Appendix D in the hope that the code may be improved and used at a later time.

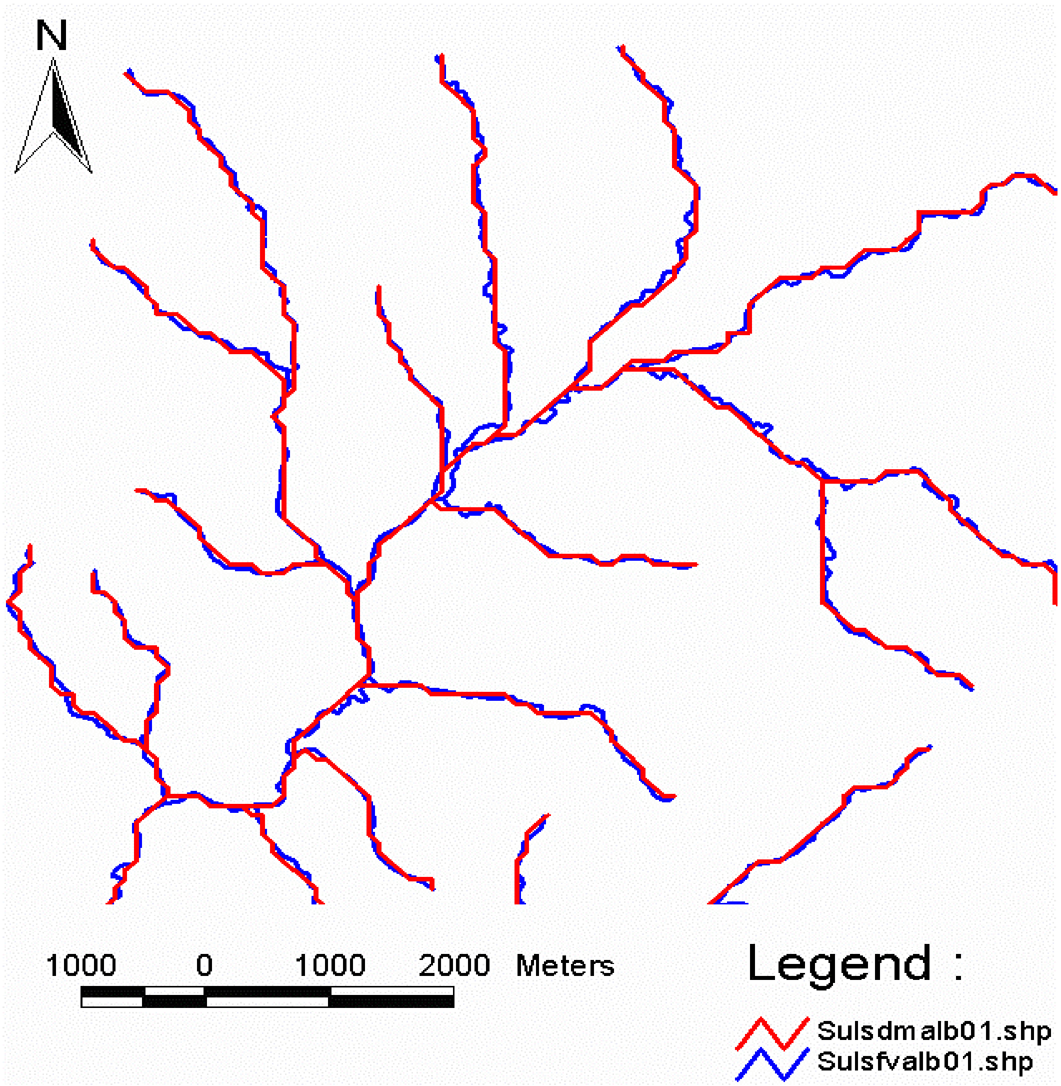


Figure 3.19 : DEM Stream Network Overlaid on Vector Stream Network

A small scale DEM cannot represent all the features defined by larger scale hydrography. The most important consequence of this effect on the project is the "short-circuiting" of mapped streams by the DEM. Short-circuiting occurs when two mapped stream segments are located within a grid cell's distance of each other. On the burned DEM these two raster stream paths will appear side by side. Wherever the gridded stream paths touch, if the elevation drop is greater between the two stream paths than in the downstream direction, the DEM defined stream will jump from one path to the other. There is no solution to this problem other than to use finer resolution DEM data.

Short-circuiting can introduce large errors into drainage area definition. The example control point shown in Figure 3.20 must be located on the DEM stream network, ***sulsdmalb01.shp***. If it is simply moved to the closest arc of the DEM stream network (due north in this case), the drainage area will be greatly over-estimated. In this situation, the drainage area would be best approximated by a control point located further downstream on the DEM stream network, where the DEM network locates the tributary. In this case, the drainage area will be slightly under-estimated. Or, if this is a fairly short tributary, the drainage area would probably best be defined by manually digitizing the watershed boundary from the DRG, as discussed in Section 3.11.

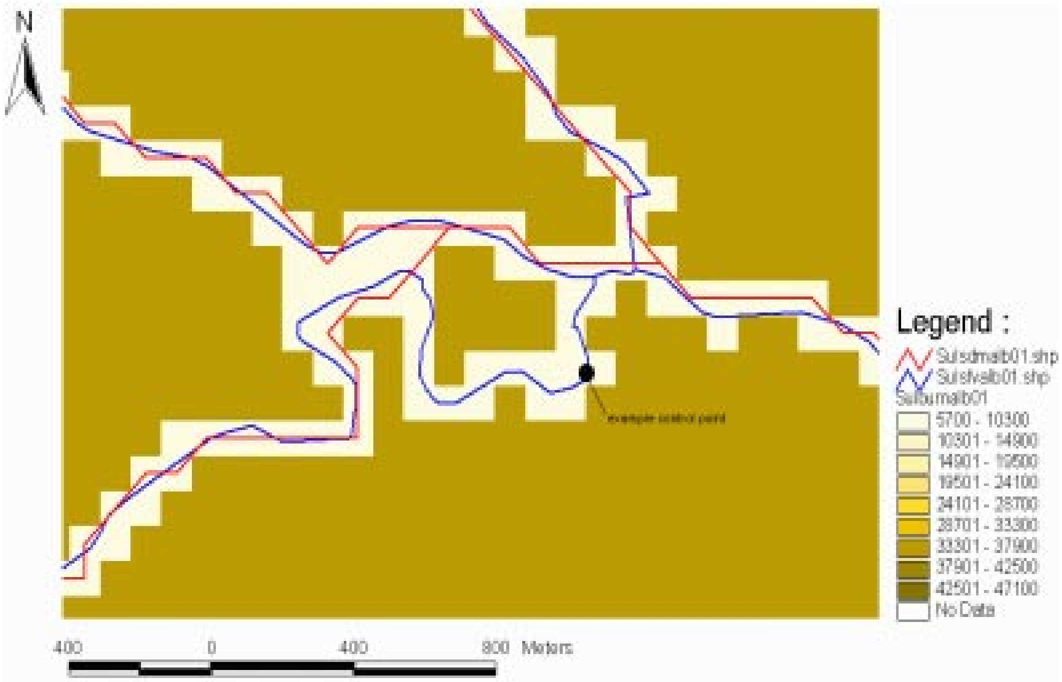


Figure 3.20 : Short-Circuiting of Mapped Stream Network by the DEM

The DEM stream network is attributed to show the connectivity among the individual arcs. This is done with the WRAP Parameters menu item “Build Stream Network Connectivity.” This menu item is based on a script developed by Qi Gu at CRWR. An identification number is assigned to each arc, and each arc then stores the identification of the next downstream arc. This script only works when all the arcs in the theme are oriented (from the from-node to the to-node) downstream. This is automatically done when the DEM stream network is created, since all of the arcs are originally drawn from a headwater node to the basin outlet.

It is possible that the DEM stream arcs will have been modified by the "clean" command. This should not happen if the fuzzy tolerance has been set to a minimum. If a change has been made in such a way that an arc is mis-oriented, the connectivity script will stop and output an error message, "wrong direction." Since the script works on the attribute table in sequential order, the error can be found by paging through the attribute table to the first arc with a downstream arc ID number of zero. Unless this arc is an outlet arc, in which case a value of zero is correct, one of the next downstream arcs is mis-oriented. The error can be found by zooming the display to the arc. Use the legend editor to draw the DEM stream theme with directional arcs. Errors can then be corrected by manually editing the stream network theme with the same procedures used on the original vector stream network.

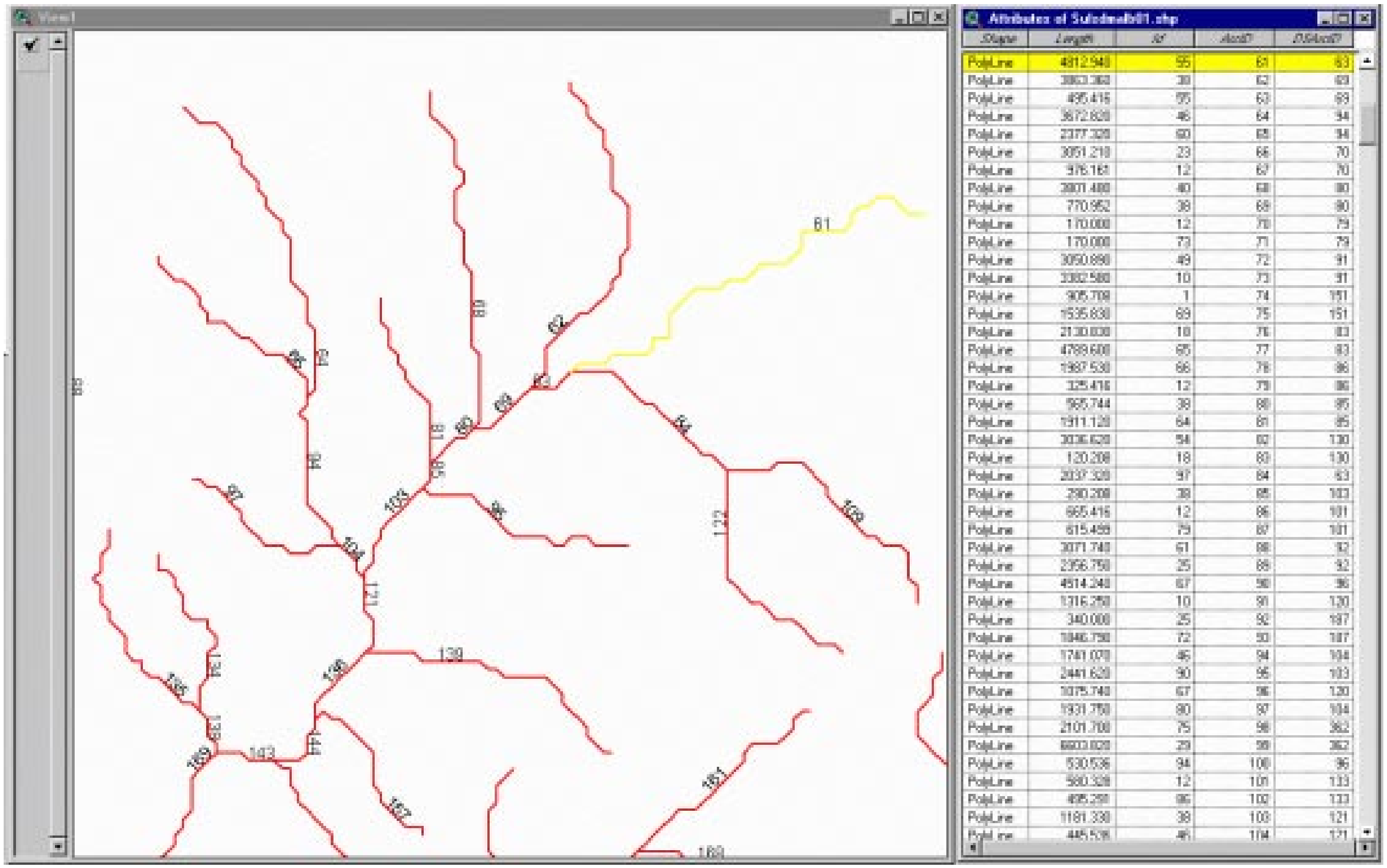


Figure 3.21 : Stream Arc Connectivity

3.7 INPUT MODEL CONTROL POINTS

The model control points must be input into the TSMS Albers projection. If there is more than one shapefile for control points in the UTM projection, they are merged. The UTM shapefile is then projected to TSMS Albers.

Arc : **shapearc *sulwruutm01 sulwruutm01***
Arc : **project cover *sulwruutm01 temp* utmtoalb.txt**
Arc : **kill *temp* all**
ArcView : **In View menu "File," click on "Manage Data Sources"**
ArcView : **Rename *temp.shp* as *sulfcpalb01.shp***

The end result of this work is to read parameters for each control point from parameter grids. The flow accumulation grid, for example, gives the drainage area at any point. To determine these parameters, the control points must be entered at the correct location on the stream network. It is imperative that the control points be located on the stream path defined by the flow direction grid and corresponding to the flow accumulation. All of the parameter grids contain values for total upstream areas and are based on the flow accumulation. With the original CRWR Prepro, this is done by simply entering a point such that it overlies the stream grid at the correct location. This is a workable approach, but for this project, the definition of the DEM stream network as a line theme provides a more secure method of locating the control points by actually attaching them to the stream arcs.

This ensures that the control points are located on the flow direction path. It also associates each control point with an arc. As points are snapped to the DEM stream network, each point recognizes the identification number of the arc it is snapped to and also the percent distance along that arc. By cross-referencing the snapped control points with the DEM stream network, which recognizes the connectivity among its arcs, the connectivity among the control points may be determined.

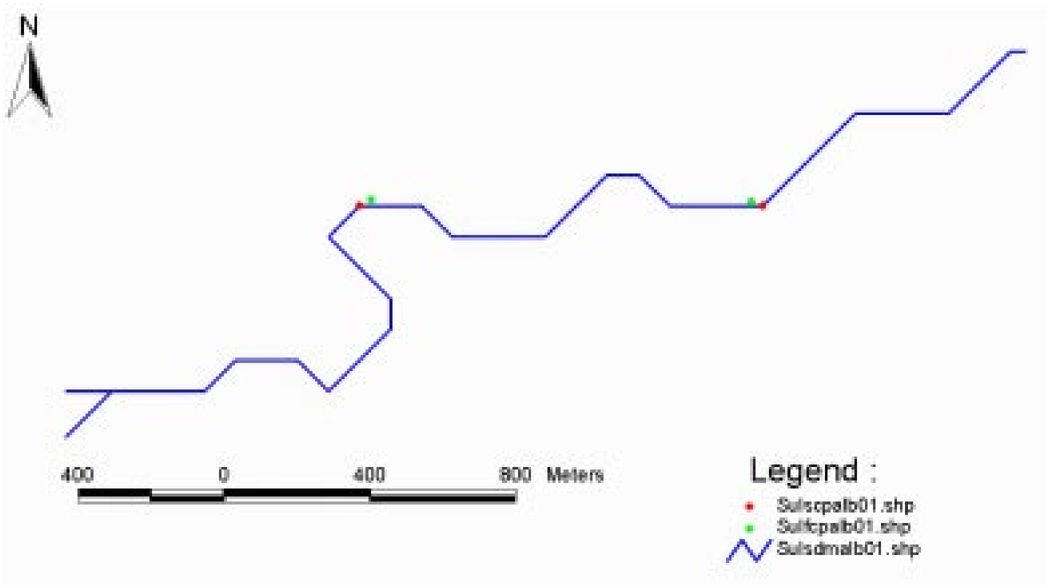


Figure 3.22 : Examples of Snapped Control Points

The entire control point theme can be snapped with the WRAP Parameters menu item, “Snap Control Points,” or individual control points can be created and snapped using the “Add Snapped Control Point” tool. Before using either of these functions, the snapped control point theme name must be entered using the WRAP Tools menu item “Set Control Point Theme Names.” Once the control points have been projected into TSMS Albers, it is possible to snap the entire theme. The snapped control points must be individually reviewed, however, to verify their correct location. The theme-snapping alogrithm is only able to pick the closest arc to a point, regardless of whether this is actually the correct arc.

Near junctions, the control point may be snapped to either upstream or downstream arcs indiscriminately. This may disrupt the correct connectivity sequence among the control points. Also, the control point may be snapped directly to the junction, when, in fact, it should be located directly upstream of the junction.

When using the theme-snapping algorithm, the user must first zoom the display to the extent of the DEM stream theme. Next, the user should zoom the display out further with two clicks of the ArcView “Zoom Out” tool. For, each point, the theme-snapping script is only able to look around at a radius of three screen pixels to find the nearest neighboring arc. If no arc is found within this radius, the point will not be snapped. Points that are not snapped are selected in the original control point coverage, and therefore highlighted in the original control point theme when the script completes it’s execution. If several control points are not snapped, the theme-snapping algorithm should be executed again with the display extent zoomed even further out. If only one or two points are not snapped it is quicker to add them with the “Add Snapped Control Point” tool, as described below.

As the snapped control point theme is reviewed, errors can be fixed by deleting an incorrect point and replacing it with the “Add Snapped Control Point” tool. This tool snaps the control point to a user-selected arc, eliminating the uncertainty in the theme-snapping algorithm. Alternately, the original control point theme can be used as a reference, and the entire snapped control point theme can be built, one point at a time, using the “Add Snapped Control Point” tool.

3.8 CREATING THE MODEL NETWORK STRUCTURE

As discussed, control points snapped to a stream network with its connectivity established have their own connectivity implicitly defined. It is possible then to create a model diagram of the control point connectivity. The WRAP model does not recognize geographic locations or a stream network, it only recognizes the sequencing of control points in the basin. The WRAP Parameters menu item "Make a Network Wire Diagram" draws a line from each control point to the next downstream control point, or to the basin outlet if there are no further downstream control points. This is a useful visualization tool, translating the geographic location of the control points along a stream network into the WRAP model view.

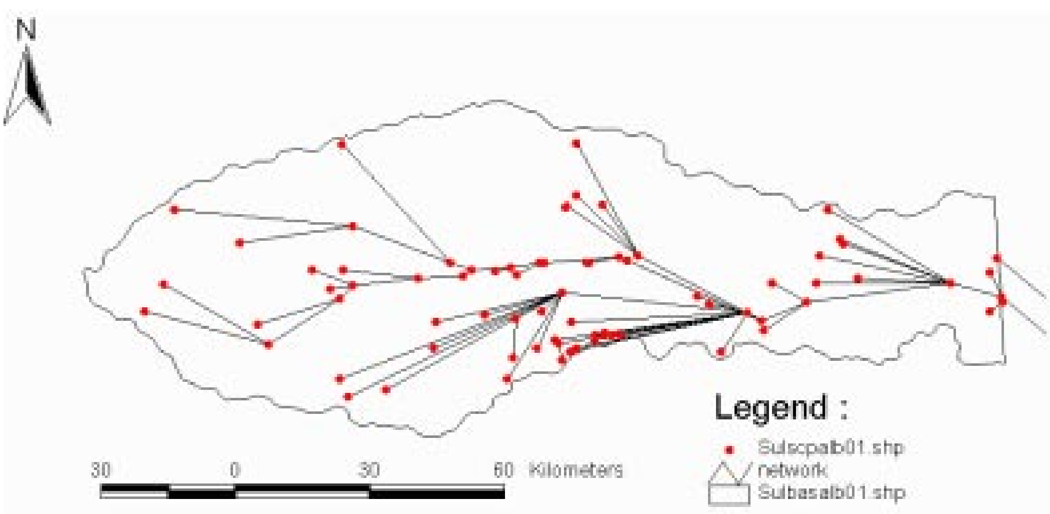


Figure 3.23 : Sulphur Basin Network Diagram

3.9 PROCESSING THE PARAMETER DATA SETS

Drainage area, average curve number, and average annual precipitation are the required flow distribution parameters for each control point. Drainage area is defined by the flow accumulation grid. The incremental watershed boundary associated with each control point is defined by the flow direction grid. These boundaries are output as a polygon shapefile, ***watersheds.shp***, with the WRAP Parameters menu item “Delineate Incremental Watersheds.” The watershed areas are first determined as grid zones from the flow direction grid. In the process of converting these grid zones to polygon boundaries, isolated “dangling polygons” are sometimes created between two grid zones. These are deleted with the WRAP Parameters menu item “Dissolve Dangling Polygons.”

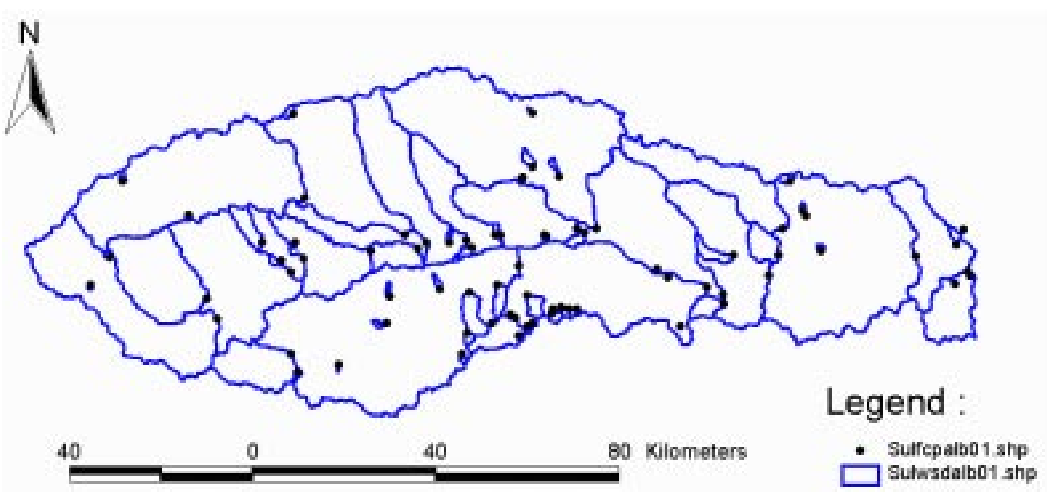


Figure 3.24 Sulphur Basin Control Point Watersheds

The average curve number may be calculated for the drainage area of any given point using a weighted flow accumulation function. The mean curve number over several areas may be calculated by dividing the sum of the products of each area and curve number by the total area.

$$mean\ curve\ number = \frac{CN_1 A_1 + CN_2 A_2 + CN_3 A_3 + ...}{A_T} \qquad (3.1)$$

A weighted flow accumulation request returns the sum of the values in all of the cells of the value grid within the flow accumulation area of the current cell. When this value is divided by the regular flow accumulation value for a cell, the average of the value grid over the upstream area is returned for each cell.

$$mean\ curve\ number = \frac{flowaccumulation(flowdirection, CN) + CN}{flowaccumulation(flowdirection) + 1} \qquad (3.2)$$

Equation 3.2 is equivalent to Equation 3.1, where each incremental area in Equation 3.1 is one grid cell. The terms CN, in the numerator, and 1, in the denominator, are included so that a cell with no flow accumulation is simply assigned its curve number value.

The WRAP Parameters menu items “Make Average Curve Number Grid” and “Make Average Precipitation Grid” apply Equation 3.2 to the original curve number and precipitation data sets. The resulting grids, ***avgcn*** and ***avgpcp***, attribute each cell with the average parameter value over that cell’s total upstream drainage area. These are temporary grids and should be copied into permanent grids.

ArcView : **In View menu “File,” click on “Manage Data Sources”**
ArcView : **Copy *avgcn* to *sulacnalb01***
ArcView : **Copy *avgpcp* to *sulapcalb01***

3.10 READING THE WRAP INPUT PARAMETERS

The flow distribution parameters are read from the parameter data sets using the WRAP Parameters menu item, "Report Control Point Parameters." Before running this function, the parameter grid theme names must be entered using the WRAP Tools menu item "Set Parameter Grid Theme Names." This script simply returns the cell value from the flow accumulation, average curve number, and average precipitation grids for each control point. The area is then calculated by multiplying the flow accumulation by the square of the cell size. The parameters are output in the attribute table of a new shapefile, ***parameters.shp***, that duplicates the snapped control point coverage. This shapefile is renamed as ***sulparalb01.shp***. Once the parameter grid theme names have been set and the grids added to the View window, the flow distribution parameters may also be queried at any point using the "Report Control Point Parameters" tool.

Attributes of Sulparalb[illegible].shp

Shape	Id	Type	[illegible]	[illegible]	Area_sq_mi	[illegible]	[illegible]	[illegible]
Point	1010	Stream gage	0	1278305	3585.3325	68.79	45.01	1278305.00
Point	1020	Diversion point	0	82	0.2287	76.43	47.00	82.00
Point	1030	Diversion point	1010	17882	49.3027	62.33	46.94	17882.00
Point	1040	Diversion point	1030	133	0.3710	57.54	47.00	133.00
Point	1050	Diversion point	1010	775	2.1616	75.55	47.00	775.00
Point	1060	Diversion point	1010	1228587	3426.6635	68.89	44.94	1228587.00
Point	1070	Diversion point	1060	173	0.4825	73.45	48.00	173.00
Point	1080	Diversion point	1060	19	0.0530	63.05	48.00	19.00
Point	1090	Diversion point	1060	147	0.4100	80.23	48.00	147.00
Point	1100	Diversion point	1060	330	0.9204	80.29	48.00	330.00
Point	1110	Diversion point	1060	36681	102.3073	78.75	48.21	36681.00
Point	1120	Diversion point	1060	5922	16.5171	72.36	47.58	5922.00
Point	1130	Diversion point	1060	1057631	2949.8486	68.84	44.52	1057631.00
Point	1140	Diversion point	1130	2618	7.3019	72.52	47.00	2618.00
Point	1150	Diversion point	1130	3529	9.8428	65.13	46.68	3529.00

Table 3.1 : Example Attributes of Parameters Shapefile

Parameters for the incremental drainage areas are calculated using the watershed polygon theme. Incremental area is automatically defined in the watershed theme. The WRAP Tools menu item, "Average Grid by Polygons," averages grid cell values within zones defined by a polygon theme and outputs the averaged values to a new field in the polygon theme. Using this menu function, incremental average curve number and precipitation are calculated from the regular curve number and precipitation grids, ***sulcngalb01*** and ***sulpcpalb01***.

3.11 QUALITY CONTROL OF DRAINAGE AREAS

Quality control of the input parameters focuses on the drainage area values. Drainage area is the dominant parameter in the flow distribution calculations. Some general limitations of DEMs in delineating watershed boundaries have already been discussed. In the methodology of drainage area delineation presented for this project, further errors may be introduced from incorrect user input of streams and control points. In a large basin, it is likely that errors will arise from poor stream definition and misplaced control points. A quality control process has been designed to limit these errors.

The quality control process presented in this section was originally developed while working on the Sulphur basin with 1:250,000 DEM data. Subsequent experience with other river basins and with 1:24,000 DEM data has exposed a weakness in this procedure. This procedure failed to recognize that short-circuiting errors in the DEM stream network, as described in Section 3.6, may introduce large errors into medium-sized drainage areas that are not specifically checked in this process. For the sake of clarity in the presentation of the methodology, the original quality control procedures, as applied to the 1:250,000 DEM data with the Sulphur basin, are presented here. An improved quality control process is presented in Section 4.5, and it is that process that should be followed when processing future river basins.

The quality control process does not check all of the drainage areas. This would be very difficult and extremely time-consuming. Instead, methods have been developed to check both the drainage areas of USGS gages, typically larger areas, and drainage areas of the smaller watersheds. Drainage areas of stream gages are compared with USGS reported values. Smaller drainage areas are compared with the DRG topography.

Drainage areas delineated by the DEM for USGS gage control points are compared with the values reported by the USGS. These values are collected in building the USGS gage shapefile for the basin, as described in Chapter 2. For the Sulphur basin, the results in Table 3.2 were calculated.

Gage	CP	USGS (sq.mi.)	DEM (sq.mi.)	Relative difference (%) $\left(\frac{USGS - DEM}{USGS}\right) * 100$
7344200	1060	3443.00	3426.66	+0.47
7344000	2010	2774.00	2802.34	-1.02
7343500	3010	494.00	536.57	-8.62
7343200	4010	1365.00	1363.34	+0.12
7343000	5010	276.00	313.09	-13.44
7342500	6010	527.00	525.42	+0.30

Table 3.2 : Analysis of USGS Gage Area Differences

Control points that show a large difference, such as 3010 and 5010 above, should be checked again for proper location on the stream network. These two points are both correctly located. In this case, the DEM drainage area value is accepted as is. These are large discrepancies, however, and some may find it hard to dismiss the USGS reported drainage area values as incorrect. As will be shown in Chapter 4, drainage areas for these two points independently defined from the 1:24,000 DEM agree closely with the 1:250,000 DEM results shown in Table 3.2. Furthermore, visual inspection of the digital watershed boundaries (from both the 1:250,000 and 1:24,000 DEM sources) delineated for these two gages shows that they agree with the DRG topography.

Experience at CRWR has shown that watersheds below 1,000 grid cells in size may have delineation errors that significantly affect the total calculated area. The watershed boundaries of all control points with flow accumulation values equal to or less than 1,000 cells are checked against the DRGs. To do this, the watershed polygons must be projected into the UTM system. Unfortunately, after the polygons are projected, they must be “cleaned” to restore polygon topology. When “clean” is applied to a polygon coverage it erases all the attributes in the polygon attribute table. This leaves the watershed polygons without any attribute of their associated control point identifier. To retain the control point identification with the watershed boundaries, the coverage is built as a line coverage rather than as polygons. Another side effect of the projection process is that dangling polygons are re-introduced into the watershed boundaries. The dangling polygons, however, are generally only one or two grid cells in size, and their presence does not adversely affect the quality control process.

Arc : **shapearc *sulwsdalb01 sulwsdalb01***
Arc : **project cover *sulwsdalb01 sulwsdutm01* albtoutm.txt**
Arc : **build *sulwsdutm01* line**
Arc : **copy *sulwsdutm01 temp***
Arc : **arcshape *temp* line *temp***
Arc : **kill *temp* all**
ArcView : **In View menu “File,” click on “Manage Data Sources”**
ArcView : **Rename *temp.shp* as *sulwsdutm01.shp***

Errors identified in the quality control process can be fixed in one of two ways. Corrections to the UTM stream network and control point locations can be made, but the basin must then be re-processed from the beginning by burning the corrected stream network into the original DEM. Errors may also be corrected by digitizing correct watershed boundaries from the DRGs and using these polygons to develop the parameters. Figure 3.25 illustrates the use of a manually digitized watershed boundary to correct an erroneous DEM delineation. If it is necessary to manually digitize watershed boundaries, a new polygon shapefile, ***sulqcwutm01.shp,*** is created for this purpose.

ArcView : **In View menu "View," click on "New Theme…"**
ArcView : **Select feature type "Polygon"**
ArcView : **Set theme name to *sulqcwutm01.shp***

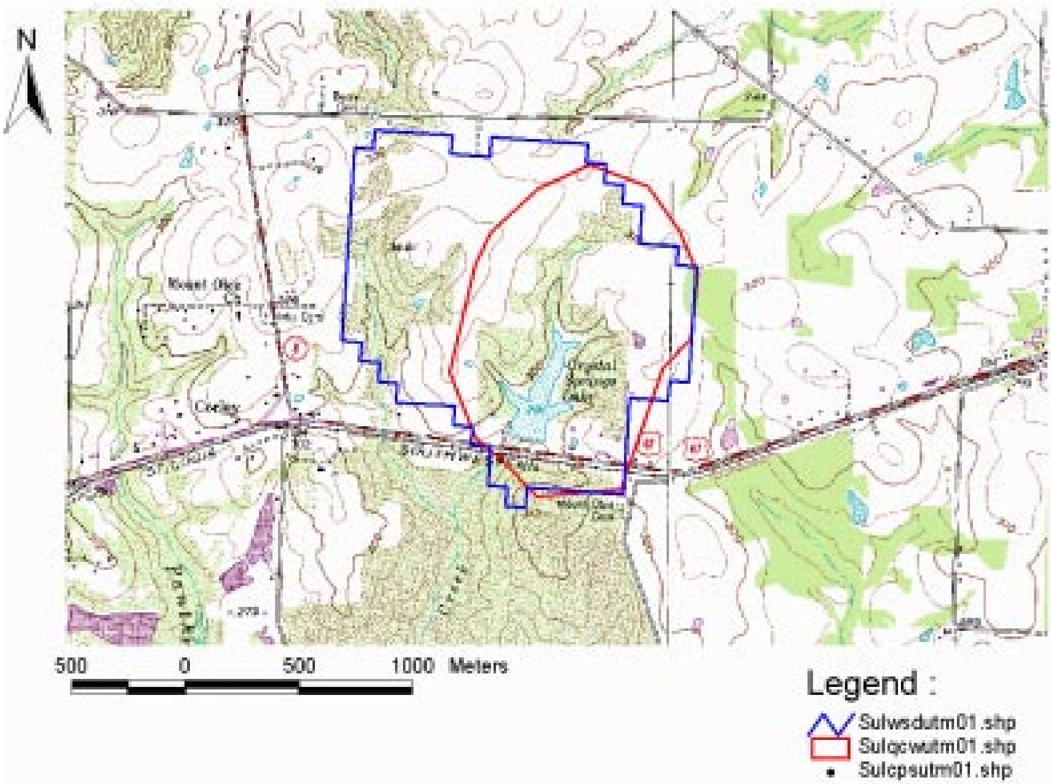


Figure 3.25 : Manually Digitized Drainage Area

In the Sulphur basin, 44 control points were reported with flow accumulation values of 1,000 cells or less. Quality control of these points found 16 watersheds with unacceptable deviations from the DRG topography. Of these 16 points, 9 errors appeared to be the primarily the result of streams that were not added to the stream network and therefore not burned into the DEM. Two errors were due to a short circuit in the DEM stream network. One control point had been incorrectly snapped. The remaining drainage area errors were simply due to the inability of the resolution of the DEM to accurately reflect the DRG topography. With a majority of the drainage area errors being the result of poor stream definition, it was necessary to correct the stream network and re-process the basin.

After correcting the stream network and re-processing the basin, the same 44 control points were found to have flow accumulation values less than or equal to 1,000 DEM cells. These points were put through the QC process a second time. Twelve drainage areas were found to disagree with the DRG topology. A watershed boundary was manually delineated for each of these points. This time, only two errors were found that could be attributed to poor stream definition. In this case, it was decided to accept the manually delineated watersheds as the final corrections to the control point parameters.

To determine parameter corrections from the quality-controlled watersheds, the theme ***sulqcwutm01.shp*** must first be projected to the TSMS Albers coordinate system. The quality control watersheds do not have an attribute field that references each polygon to its respective control point. After projecting the polygons, it is necessary to manually enter a control point identification for each shape. This can be done by editing the theme attribute table. As a result of cleaning the watershed coverage after the projection step, some extraneous polygons may be created between watershed polygons with connecting arcs. These are identified and deleted during the process of identifying and adding control point identifiers to each polygon.

Arc : **shapearc *sulqcwutm01 sulqcwutm01***
Arc : **project cover *sulqcwutm01 sulqcwalb01* utmtoalb.txt**
Arc : **clean *sulqcwalb01***
Arc : **build *sulqcwalb01***
Arc : **copy *sulqcwalb01 temp***

Arc : **arcshape *temp* poly *temp***
Arc : **kill *temp* all**
ArcView : **In View menu "File," click on "Manage Data Sources"**
ArcView : **Rename *temp.shp* as *sulqcwalb01.shp***

Incremental parameters are determined for the quality-controlled watersheds in the same manner as with the incremental watershed theme. Table 3.3 shows the resulting attribute table for ***sulqcwalb01.shp***. In this case, the area of each polygon is not automatically reported in units of square miles, rather it is given in map units of square meters, and must be converted by the user. These values are substituted as the final parameter values. Care should be taken to adjust upstream and/or downstream drainage area values if this substitution represents a significant change.

Attributes of Sulqcwalb01.shp

Shape	Area	Perimeter	Temp_	Temp_id	Incavgcn	Incavgpcp	Cp
Polygon	7614684.000	11290.080	3	0	75.8855	47.0000	1050
Polygon	4694355.000	10109.270	8	0	71.2278	47.0000	2040
Polygon	1910800.000	5478.784	6	0	75.7266	47.0000	2050
Polygon	171647.800	1712.614	10	0	63.4000	46.0000	2060
Polygon	521268.100	2997.252	11	0	70.3513	46.0000	2140
Polygon	1327664.000	4568.627	13	0	72.6848	45.0000	2170
Polygon	196491.200	2220.482	4	0	67.7241	46.3448	2240
Polygon	4003953.000	8314.236	12	0	79.5027	44.0000	3050
Polygon	4641212.000	10518.400	9	0	70.9199	43.0000	3070
Polygon	1328761.000	4537.387	14	0	72.8541	45.0000	3100
Polygon	530665.900	2805.503	5	0	71.8082	43.0000	4110
Polygon	1394995.000	4657.915	2	0	73.1263	43.0000	5020

Table 3.3 : Attributes of Manually Delineated Watersheds

Chapter 4 : Results and Discussion

4.1 STREAM NETWORK CONSTRUCTION

In this work, stream networks have been prepared by adding streams from 1:24,000 scale DRGs to those originally identified by the 1:100,000 scale RF3. The resulting network closely conforms to the hydrography of the 1:24,000 scale DRGs. Small watersheds cannot be accurately defined from 1:250,000 scale DEMs without burning in streams identified from larger scale hydrography. Even this does not guarantee accurate watershed delineation. In fact, burning streams of larger scale than the DEM introduces the possibility for large drainage area errors from short-circuiting of the burned stream channels.

The method of constructing the stream network is straight forward. For the most part, existing ArcView editing tools are used to digitize new features and snap them to existing features. The stream network topology can be corrected without using ArcInfo, by using ArcView's Vertex Editor tool and the WRAP Parameters Erase Interior Dangling Nodes tool. Every effort should be made to find and digitize all streams before burning and processing the DEM. A large number of drainage area errors identified in the quality control process as resulting from poor stream definition will require re-processing the DEM from the beginning.

The vector stream network can be translated into the DEM stream network with the WRAP Parameters menu item, "Define the DEM Stream Network." It is necessary to run the ArcInfo "clean" process on the original coverage of DEM streams to reduce the overlapping lines. With small scale DEMs, clean has never altered the topology of the original stream segments, other than to remove overlapping arcs. With the finer resolution DEMs, clean may alter the arc topology. Setting the tolerance for the clean command to a minimum should prevent this, but the user should always be prepared for clean to introduce errors into the resulting stream network. Changes to the topology will produce errors in the subsequent procedure for ordering the stream segments. The topology can be fixed as each error is identified although this is a somewhat time-consuming process.

Constructing the stream network is possibly the most time-intensive task in preparing the WRAP model flow distribution parameters. The Texas Natural Resources Information System (TNRIS) is currently developing 1:24,000 scale hydrography coverages for the entire state of Texas. The availability of this data set will greatly speed the processing of a river basin.

4.2 FLOW DISTRIBUTION PARAMETERS

Table 4.1 lists the flow distribution parameters obtained for the Sulphur basin, using the 1:250,000 scale DEM. These parameters may differ slightly from those used in the final WRAP model of the basin. The WRAP model was finalized in January of 1999. The processing of the basin presented in this thesis reflects several changes in the methodology since the parameters were originally prepared. Slight changes in the flow distribution parameters should be expected any time a basin is processed again. When a basin is reprocessed, control point

				TOTAL AREAS			INCREMENTAL AREAS			QC AREAS		
CP	TYPE	DSCP	DEMFAC	AREA	CN	PCP	AREA	CN	PCP	AREA	CN	PCP
1010	Other Primary	0	1278305	3565.3325	69.79	45.01	86.5991	70.0291	46.7727			
1020	Diversion point	0	82	0.2287	76.43	47	0.2315	76.4337	47			
1030	Diversion point	1010	17892	49.9027	62.33	46.94	49.5318	62.3913	46.9374			
1040	Diversion point	1030	133	0.371	57.54	47	0.3737	57.5448	47			
1050	Diversion point	1010	775	2.1616	75.55	47	2.1643	75.4936	47	2.9400	75.8855	47
1060	Diversion point	1010	1228587	3426.6635	69.89	44.94	356.1079	74.2424	47.3265			
1070	Diversion point	1060	173	0.4825	73.45	48	0.4853	73.4483	48			
1080	Diversion point	1060	19	0.053	63.05	48	0.0558	63.05	48			
1090	Diversion point	1060	147	0.41	80.23	48	0.4128	80.2297	48			
1100	Diversion point	1060	330	0.9204	80.29	48	0.9232	80.287	48			
1110	Diversion point	1060	36681	102.3073	78.75	48.21	102.3073	78.7541	48.2085			
1120	Diversion point	1060	5922	16.5171	72.36	47.58	16.5199	72.2573	47.5735			
1130	Diversion point	1060	1057631	2949.8486	69.04	44.52	130.3602	71.0067	47.4152			
1140	Diversion point	1130	2618	7.3019	72.52	47	7.3047	72.5233	47			
1150	Diversion point	1130	3529	9.8428	65.13	46.68	9.8456	65.1499	46.6777			
2010	Stream gage	1130	1004743	2802.3381	68.95	44.37	177.7248	67.0421	47.3184			
2020	Diversion point	2010	284222	792.7262	69.43	44.66	223.9906	65.7148	45.9235			
2030	Diversion point	2020	332	0.926	78.55	46	0.9288	78.5496	46			
2040	Diversion point	2020	585	1.6316	72.95	47	1.0599	71.3089	47	1.8125	71.2278	47
2050	Diversion point	2040	205	0.5718	75.87	47	0.5746	75.8738	47	0.7378	75.7266	47
2060	Diversion point	2020	125	0.3486	66.42	46	0.3514	66.4206	46	0.0663	63.4	46
2070	Diversion point	2020	324	0.9037	46.82	46	0.9065	46.8154	46			
2080	Diversion point	2020	43	0.1199	59.36	46	0.092	59.3636	46			
2090	Diversion point	2080	10	0.0279	59.36	46	0.0307	59.3636	46			
2100	Diversion point	2020	170	0.4741	69.5	46	0.4769	69.5029	46			
2110	Diversion point	2020	88	0.2454	68.65	46	0.2482	68.6517	46			
2120	Diversion point	2020	2010	5.6061	69.61	45.31	5.6089	69.6116	45.3098			
2130	Diversion point	2020	21	0.0586	69	45	0.0614	69	45			
2140	Diversion point	2020	31	0.0865	70.19	46	0.0893	70.1875	46	0.2013	70.3513	46

Table 4.1 : Flow Distribution Parameters using 1:250,000 DEM

				TOTAL AREAS			INCREMENTAL AREAS			QC AREAS		
CP	TYPE	DSCP	DEMFAC	AREA	CN	PCP	AREA	CN	PCP	AREA	CN	PCP
2150	Diversion point	2020	50	0.1395	70	46	0.1422	70	46			
2160	Diversion point	2020	7743	21.5961	72.66	44.81	20.9044	72.6499	44.8045			
2170	Diversion point	2160	248	0.6917	72.73	45	0.6945	72.7309	45	0.5126	72.6848	45
2180	Diversion point	2010	133730	372.9876	67.92	45.78	368.7677	67.9153	45.7811			
2190	Diversion point	2180	432	1.2049	69.8	46	1.2077	69.8044	46			
2200	Diversion point	2180	96	0.2678	73.63	45	0.2705	73.6289	45			
2210	Diversion point	2180	843	2.3512	67.73	45.84	2.354	67.7767	45.8402			
2220	Diversion point	2180	139	0.3877	63.71	45.02	0.053	62.4737	45			
2230	Diversion point	2220	120	0.3347	63.91	45.02	0.3375	63.9091	45.0248			
2240	Diversion point	2010	42	0.1171	69.74	46.07	0.1199	69.7442	46.0698	0.0759	67.7241	46.3448
2250	Diversion point	2010	523025	1458.7739	69.18	43.5	94.7935	65.2929	44.8655			
2260	Diversion point	2250	33	0.092	51.24	46	0.0948	51.2353	46			
2270	Diversion point	2250	194	0.5411	54.3	45.95	0.5439	54.2974	45.9538			
3010	Stream gage	2020	192379	536.5661	70.86	44.11	59.1208	68.3048	43.5891			
3020	Diversion point	3010	2239	6.2448	69.07	44.21	6.2476	69.067	44.2129			
3030	Diversion point	3010	5	0.0139	70	45	0.0167	70	45			
3040	Diversion point	3010	168936	471.181	71.21	44.17	408.1945	71.1713	44.1484			
3050	Diversion point	3040	601	1.6763	78.62	44	1.679	78.6246	44	1.5459	79.5027	44
3060	Diversion point	3040	274	0.7642	72.4	44	0.767	72.4	44			
3070	Diversion point	3040	408	1.138	71.34	43	1.1407	71.5349	43	1.7920	70.9199	43
3080	Diversion point	3040	322	0.8981	68.02	44	0.9009	68.0155	44			
3090	Diversion point	3040	389	1.085	65.4	44	1.0878	65.4026	44			
3100	Diversion point	3040	86	0.2399	74.68	45	0.2427	74.6782	45	0.5130	72.8541	45
3110	Diversion point	3040	252	0.7029	85.74	45	0.7056	85.7391	45			
3120	Diversion point	3040	20244	56.4627	71.18	44.35	56.4655	71.1796	44.3483			
4010	Stream gage	2250	488809	1363.3418	69.46	43.4	1.6958	62.5536	44			
4020	Diversion point	4010	488201	1361.646	69.47	43.4	69.7696	68.7206	44.0222			
4030	Diversion point	4020	984	2.7445	67.36	43	2.7473	67.3936	43			

Table 4.1 : Flow Distribution Parameters using 1:250,000 DEM

				TOTAL AREAS			INCREMENTAL AREAS			QC AREAS		
CP	TYPE	DSCP	DEMFAC	AREA	CN	PCP	AREA	CN	PCP	AREA	CN	PCP
4040	Diversion point	4020	462201	1289.1292	69.51	43.37	126.8877	69.3267	44.3777			
4050	Diversion point	4040	2152	6.0022	69.04	43.03	6.005	69.0046	43.0337			
4060	Diversion point	4040	414554	1156.2365	69.54	43.26	46.8821	69.1731	43.8911			
4070	Diversion point	4060	224056	624.9167	69.12	42.87	21.7662	68.6395	43.8183			
4080	Diversion point	4070	216252	603.1505	69.14	42.84	77.4117	67.7763	43.8561			
4090	Diversion point	4060	173688	484.4348	70.11	43.7	170.0018	70.2384	44.62			
4100	Diversion point	4090	479	1.336	70.5	45	1.3388	70.5042	45			
4110	Diversion point	4080	115	0.3207	72.66	43	0.3235	72.6552	43	0.2049	71.8082	43
5010	Stream Gage	4090	112256	313.0943	70.03	43.19	312.0735	70.019	43.1932			
5020	Diversion point	5010	134	0.3737	74.4	43	0.3765	74.4	43	0.5386	73.1263	43
5030	Diversion point	5010	231	0.6443	73.89	43	0.6471	73.8879	43			
6010	Stream Gage	4080	188381	525.4152	69.34	42.69	27.6624	69.7687	43.3645			
6020	Diversion point	6010	519	1.4475	70.97	43.16	1.4503	70.9217	43.1676			
6030	Diversion point	6010	4465	12.4534	69.81	43	12.4562	69.8205	43			
6040	Diversion point	6010	173477	483.8463	69.3	42.64	170.5317	68.6886	43.3673			
6050	Diversion point	6040	39742	110.8448	70.08	42.41	110.8476	70.0837	42.4138			
6060	Diversion point	6040	72592	202.467	69.38	42.15	201.2259	69.3673	42.1474			
6070	Diversion point	6060	326	0.9092	72.29	42	0.912	72.2875	42			
6080	Diversion point	6060	118	0.3291	69.45	42	0.3319	69.4454	42			

Table 4.1 : Flow Distribution Parameters using 1:250,000 DEM

positions often change slightly due to changes in the DEM stream network and changes in the snapped control point locations.

The resulting drainage area parameters have been discussed in Section 3.11. The quality control process in that section addresses only the small and large drainage areas. In performing quality control, it was originally felt that the remaining drainage area values could be accepted as is. It is difficult to compare larger watershed boundaries with the DRG topography and there is no other readily available source (such as that for USGS reported gage areas) for comparison of the drainage area values. When the parameters were prepared with 1:24,000 DEM data, however, some large discrepancies were noted in drainage area values. These discrepancies highlight further difficulties in delineating watersheds with 1:250,000 scale DEMs. These difficulties are discussed in Section 4.4, where areas delineated from the 1:250,000 DEM are compared to those delineated from the 1:24,000 DEM.

The precipitation parameter is not analyzed in this study. The limitations in defining this parameter for small watersheds from the small scale of the source data have been discussed in Section 1.3.2. It is worth re-stating the PRISM precipitation grid metadata here: "point precipitation can be estimated at a spatial precision no better than 2 km," [but] "the overall distribution of precipitation features is thought to be accurate." The precipitation parameter represents a small adjustment in the flow distribution and only applies to watersheds that are located some distance apart. The PRISM precipitation data is suitable for this purpose.

Curve numbers must be accepted as is, considering the resolution of the source data. In the Sulphur Basin, six control points report curve numbers lower than 60 (the lowest being 47.) The contractor modeling the basin questioned the accuracy of these values (R.J. Brandes Co., 1999). The drainage areas of these control points range from 0.03 mi.^{2} to 0.9 mi.^{2}. The discussion of curve number parameters in Section 1.3.2 cautions that there may be a loss in precision of the curve number values estimated for small watersheds from 1:250,000 scale source data.

Curve numbers of this magnitude are certainly possible, though they generally only appear in areas of poor hydrologic soils, and examination of these watersheds reveals little indication that the curve numbers should be otherwise. Figures 4.1 and 4.2 show two of these watersheds (control points 2260 and 2270) overlaid on the curve number grid and DRG maps.

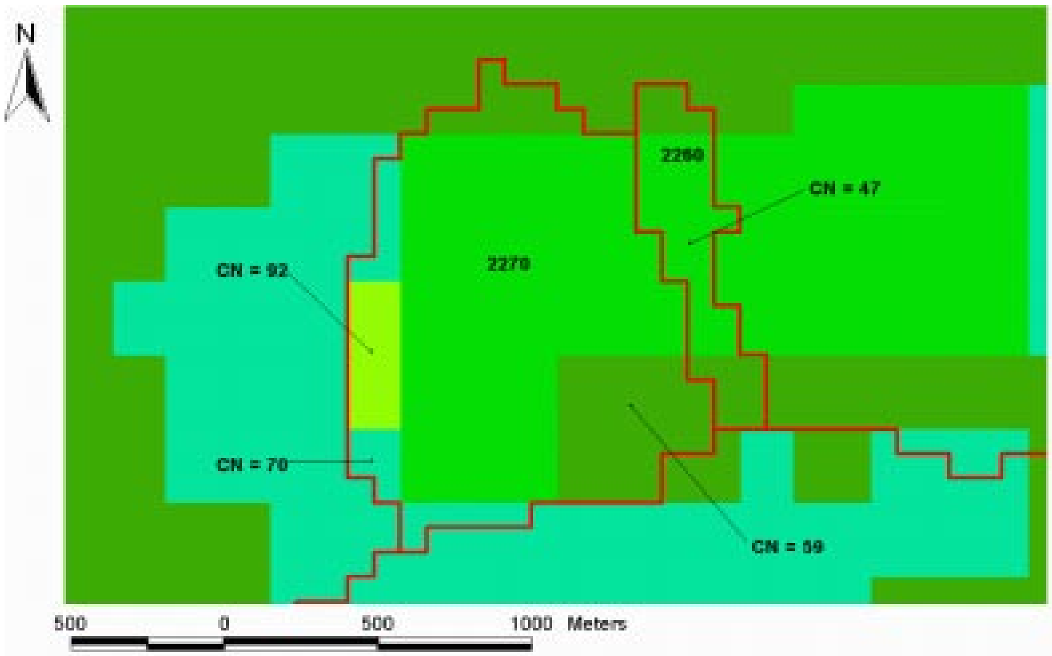


Figure 4.1 : CP 2260 and 2270 Watersheds Overlaid on Curve Number Grid

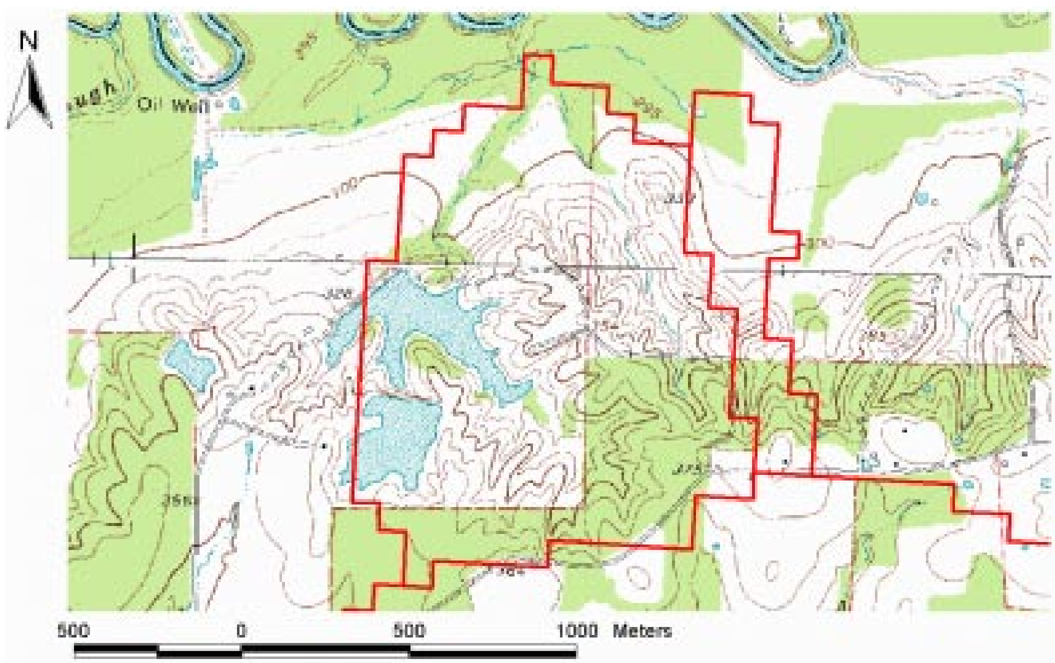


Figure 4.2 : CP 2260 and 2270 Watersheds Overlaid on DRG

4.3 PREPARING PARAMETERS WITH 1:24,000 SCALE DEMS

In early 1999, 1:24,000 scale DEMs became available for the entire state of Texas as part of the National Elevation Database (NED) project. They represent a considerable improvement over the existing 1:250,000 scale DEMs. The use of these 1:24,000 DEMs, however, requires larger file sizes and increased processing times. The 1:24,000 DEM for the Sulphur Basin requires 35.2 megabytes of storage space, compared to 2.5 megabytes for the 1:250,000 scale DEM.

NED DEMs come packaged on CD-ROMs as 1°x1° latitude by longitude grids. Each CD contains up to nine grids. The individual grids are processed and merged similarly to the procedure used for 1:250,000 DEMs in Section 2.2. For the Sulphur basin, this was accomplished by an ArcInfo AML, "dem30m.txt" Each grid is converted to an integer grid, and the results are merged.

To save time, the merged DEM should be clipped to the buffered basin extent before projecting it. To do this, the buffered basin must be projected into the DEM projection. The original NED DEMs are given in a geographic projection, with NAD83 datum, GRS1980 spheroid, coordinate units of decimal degrees, and elevation units of meters (stored as floating point values). The resulting DEM is projected into the TSMS Albers coordinate system.

The 1:24,000 DEM is burned with the combined internal and external vector stream networks, ***sulsbnalb01.shp***, and is processed according to the methodology of Chapter 3. The results are given in Section 4.4 where they are compared to those obtained from the small scale DEMs. The resulting drainage areas were quality controlled by the methods given in section 3.12. For the gage watersheds, the following areas were obtained :

Gage	CP	USGS (sq.mi.)	1:250,000 DEM (sq.mi.)	%Difference $\left(\frac{USGS - DEM}{USGS}\right)*100$	1:24,000 DEM (sq.mi.)	%Difference $\left(\frac{USGS - DEM}{USGS}\right)*100$
7344200	1060	3443.00	3426.66	+0.47	3412.15	+0.90
7344000	2010	2774.00	2802.34	-1.02	2789.83	-0.57
7343500	3010	494.00	536.57	-8.62	537.64	-8.83
7343200	4010	1365.00	1363.34	+0.12	1355.35	+0.71
7343000	5010	276.00	313.09	-13.44	305.08	-10.54
7342500	6010	527.00	525.42	+0.30	523.59	+0.65

Table 4.2 : Comparison of Gage Drainage Areas

The results are similar to those obtained with the 1:250,000 scale DEM. In general the agreement between USGS and DEM values is very close, except for control points 3010 and 5010. Again, these points were found to be correctly located. Furthermore, the DEM watershed boundaries for these two points were compared to the DRG topography and appear to be correct. The agreement between the results of the two DEMs, two independently developed data sources, suggests that the USGS reported values are in error. It is also possible that the USGS values may have been calculated at a past time when the basin hydrography was different.

Twelve points report flow accumulation values less than 1,000 cells. When these watershed boundaries were checked against the DEM, no significant errors were found. In fact, the drainage areas are so well delineated, that the user must be very careful in exactly locating the control point. Even small terrain features, such as swales with no mapped streams, are defined by the 1:24,000 DEM.

4.4 COMPARISON OF RESULTS BETWEEN LARGE AND SMALL SCALE DEMS

The 1:24,000 scale DEM parameters are given in Table 4.3. They are compared against the parameters obtained from the 1:250,000 scale DEM. Differences are given as the absolute difference of the 1:24,000 DEM value subtracted from the 1:250,000 value. Results for the precipitation parameters are not discussed. Table 4.3 shows that the differences in precipitation parameters between the two DEM scales are negligible.

	1:250,000 scale DEM				1:24,000 scale DEM					
CP	AREA	CN	PCP		AREA	CN	PCP	ΔAREA	ΔCN	ΔPCP
1010	3565.3325	69.79	45.01	1010	3545.8166	69.81	45	19.5159	-0.02	0.01
1020	0.2287	76.43	47	1020	0.7731	73.22	47	-0.5444	3.21	0
1030	49.9027	62.33	46.94	1030	44.6097	62.54	46.93	5.293	-0.21	0.01
1040	0.371	57.54	47	1040	0.4881	56.39	47	-0.1171	1.15	0
1050	2.9400	75.8855	47	1050	3.0648	76.14	47	-0.1247553	-0.2545	0
1060	3426.6635	69.89	44.94	1060	3412.1487	69.91	44.93	14.5148	-0.02	0.01
1070	0.4825	73.45	48	1070	0.3251	73.44	48	0.1574	0.01	0
1080	0.053	63.05	48	1080	0.0168	57.09	48	0.0362	5.96	0
1090	0.41	80.23	48	1090	0.4722	80.35	48	-0.0622	-0.12	0
1100	0.9204	80.29	48	1100	0.8222	79.95	48	0.0982	0.34	0
1110	102.3073	78.75	48.21	1110	102.1641	78.78	48.2	0.1432	-0.03	0.01
1120	16.5171	72.36	47.58	1120	17.8039	72.72	47.56	-1.2868	-0.36	0.02
1130	2949.8486	69.04	44.52	1130	2935.5219	69.05	44.51	14.3267	-0.01	0.01
1140	7.3019	72.52	47	1140	8.7021	72.18	47	-1.4002	0.34	0
1150	9.8428	65.13	46.68	1150	10.0021	65.57	46.66	-0.1593	-0.44	0.02
2010	2802.3381	68.95	44.37	2010	2789.832	68.95	44.36	12.5061	0	0.01
2020	792.7262	69.43	44.66	2020	798.5698	69.46	44.65	-5.8436	-0.03	0.01
2030	0.926	78.55	46	2030	0.8661	76.48	46	0.0599	2.07	0
2040	1.8125	71.2278	47	2040	3.1644	72.01	47	-1.3519001	-0.7822	0
2050	0.7378	75.7266	47	2050	1.132	73.74	47	-0.3942363	1.9866	0
2060	0.0663	63.4	46	2060	0.0843	64.14	46	-0.0180264	-0.74	0
2070	0.9037	46.82	46	2070	0.6751	44.38	46	0.2286	2.44	0
2080	0.1199	59.36	46	2080	0.0939	59.72	46	0.026	-0.36	0
2090	0.0279	59.36	46	2090	0.0289	67.52	46	-0.001	-8.16	0
2100	0.4741	69.5	46	2100	0.3634	69.44	46	0.1107	0.06	0
2110	0.2454	68.65	46	2110	0.2604	68.78	46	-0.015	-0.13	0
2120	5.6061	69.61	45.31	2120	4.7404	69.47	45.29	0.8657	0.14	0.02
2130	0.0586	69	45	2130	0.0479	66.1	45	0.0107	2.9	0

Table 4.3 : Comparison of Flow Distribution Parameters

	1:250,000 scale DEM				1:24,000 scale DEM					
CP	AREA	CN	PCP		AREA	CN	PCP	ΔAREA	Δ CN	ΔPCP
2140	0.2013	70.3513	46	2140	0.1997	70.46	46	0.0015627	-0.1087	0
2150	0.1395	70	46	2150	0.3537	70.19	46	-0.2142	-0.19	0
2160	21.5961	72.66	44.81	2160	21.965	72.49	44.8	-0.3689	0.17	0.01
2170	0.5126	72.6848	45	2170	0.5015	72.18	45	0.0111137	0.5048	0
2180	372.9876	67.92	45.78	2180	364.1704	67.97	45.76	8.8172	-0.05	0.02
2190	1.2049	69.8	46	2190	1.8855	69.34	46	-0.6806	0.46	0
2200	0.2678	73.63	45	2200	0.3773	72.19	45	-0.1095	1.44	0
2210	2.3512	67.73	45.84	2210	2.9469	68.07	45.74	-0.5957	-0.34	0.1
2220	0.3877	63.71	45.02	2220	0.3363	64.07	45.01	0.0514	-0.36	0.01
2230	0.3347	63.91	45.02	2230	0.2846	64.52	45	0.0501	-0.61	0.02
2240	0.0759	67.7241	46.3448	2240	0.0915	67.32	46.35	-0.0156344	0.4041	-0.0052
2250	1458.7739	69.18	43.5	2250	1449.6671	69.17	43.5	9.1068	0.01	0
2260	0.092	51.24	46	2260	0.0078	56.23	46	0.0842	-4.99	0
2270	0.5411	54.3	45.95	2270	0.5099	55.91	45.91	0.0312	-1.61	0.04
3010	536.5661	70.86	44.11	3010	537.6414	70.89	44.1	-1.0753	-0.03	0.01
3020	6.2448	69.07	44.21	3020	5.7965	68.28	44.18	0.4483	0.79	0.03
3030	0.0139	70	45	3030	0.0065	70	45	0.0074	0	0
3040	471.181	71.21	44.17	3040	476.8688	71.21	44.17	-5.6878	0	0
3050	1.5459	79.5027	44	3050	1.6096	79.38	44	-0.0636657	0.1227	0
3060	0.7642	72.4	44	3060	0.8552	72.57	44	-0.091	-0.17	0
3070	1.7920	70.9199	43	3070	1.8504	70.43	43	-0.0584188	0.4899	0
3080	0.8981	68.02	44	3080	0.6536	66.5	44	0.2445	1.52	0
3090	1.085	65.4	44	3090	1.0384	65.87	44	0.0466	-0.47	0
3100	0.5130	72.8541	45	3100	0.5575	72.4	45	-0.0444627	0.4541	0
3110	0.7029	85.74	45	3110	0.6436	85.91	45	0.0593	-0.17	0
3120	56.4627	71.18	44.35	3120	61.2398	70.98	44.28	-4.7771	0.2	0.07
4010	1363.3418	69.46	43.4	4010	1355.3534	69.44	43.4	7.9884	0.02	0
4020	1361.646	69.47	43.4	4020	1355.1854	69.45	43.4	6.4606	0.02	0
4030	2.7445	67.36	43	4030	4.8663	67.74	43	-2.1218	-0.38	0

Table 4.3 : Comparison of Flow Distribution Parameters

	1:250,000 scale DEM				1:24,000 scale DEM					
CP	AREA	CN	PCP		AREA	CN	PCP	ΔAREA	Δ CN	ΔPCP
4040	1289.1292	69.51	43.37	4040	1276.0708	69.5	43.37	13.0584	0.01	0
4050	6.0022	69.04	43.03	4050	5.2841	69.39	43	0.7181	-0.35	0.03
4060	1156.2365	69.54	43.26	4060	1147.2592	69.53	43.26	8.9773	0.01	0
4070	624.9167	69.12	42.87	4070	38.5201	67.89	43.88	586.3966	1.23	-1.01
4080	603.1505	69.14	42.84	4080	11.9598	65.97	44	591.1907	3.17	-1.16
4090	484.4348	70.11	43.7	4090	468.1801	70.1	43.71	16.2547	0.01	-0.01
4100	1.336	70.5	45	4100	1.3859	70.52	45	-0.0499	-0.02	0
4110	0.2049	71.8082	43	4110	0.2	72.94	43	0.0048912	-1.1318	0
5010	313.0943	70.03	43.19	5010	305.0755	70	43.19	8.0188	0.03	0
5020	0.5386	73.1263	43	5020	0.5951	72.83	43	-0.0564896	0.2963	0
5030	0.6443	73.89	43	5030	0.7535	73.5	43	-0.1092	0.39	0
6010	525.4152	69.34	42.69	6010	523.5883	69.34	42.67	1.8269	0	0.02
6020	1.4475	70.97	43.16	6020	1.5971	70.75	43.16	-0.1496	0.22	0
6030	12.4534	69.81	43	6030	11.8963	69.76	43	0.5571	0.05	0
6040	483.8463	69.3	42.64	6040	478.8912	69.33	42.61	4.9551	-0.03	0.03
6050	110.8448	70.08	42.41	6050	109.3406	69.83	42.4	1.5042	0.25	0.01
6060	202.467	69.38	42.15	6060	206.1499	69.55	42.15	-3.6829	-0.17	0
6070	0.9092	72.29	42	6070	0.8928	72.34	42	0.0164	-0.05	0
6080	0.3291	69.45	42	6080	0.3366	69.71	42	-0.0075	-0.26	0

Table 4.3 : Comparison of Flow Distribution Parameters

Two control points, 4070 and 4080, report very large changes in drainage areas. An examination of these two points, shown on the following pages in Figures 4.3 and 4.4, reveals that the 1:250,000 DEM watersheds are incorrect. There is a large short-circuiting error in the DEM stream definition just upstream of these points that temporarily sidetracks the North Sulphur River into a tributary where control points 4070 and 4080 are located. The drainage areas of these two points are therefore grossly over-estimated in the 1:250,000 DEM parameters. This short-circuit is corrected in the 1:24,000 DEM stream definition. Note that while the incremental drainage area of the next downstream control point, CP 4060, is affected by this error, the value of the total drainage area used for flow distribution is not, as can be seen in Table 4.3.

Finding this short-circuiting error exposed a major problem with the quality control procedures established for the 1:250,000 DEM. It is not enough to just check the large and small watersheds. All watersheds are subject to this type of short-circuiting error. An improved quality control procedure is presented in Section 4.5 to prevent this type of error.

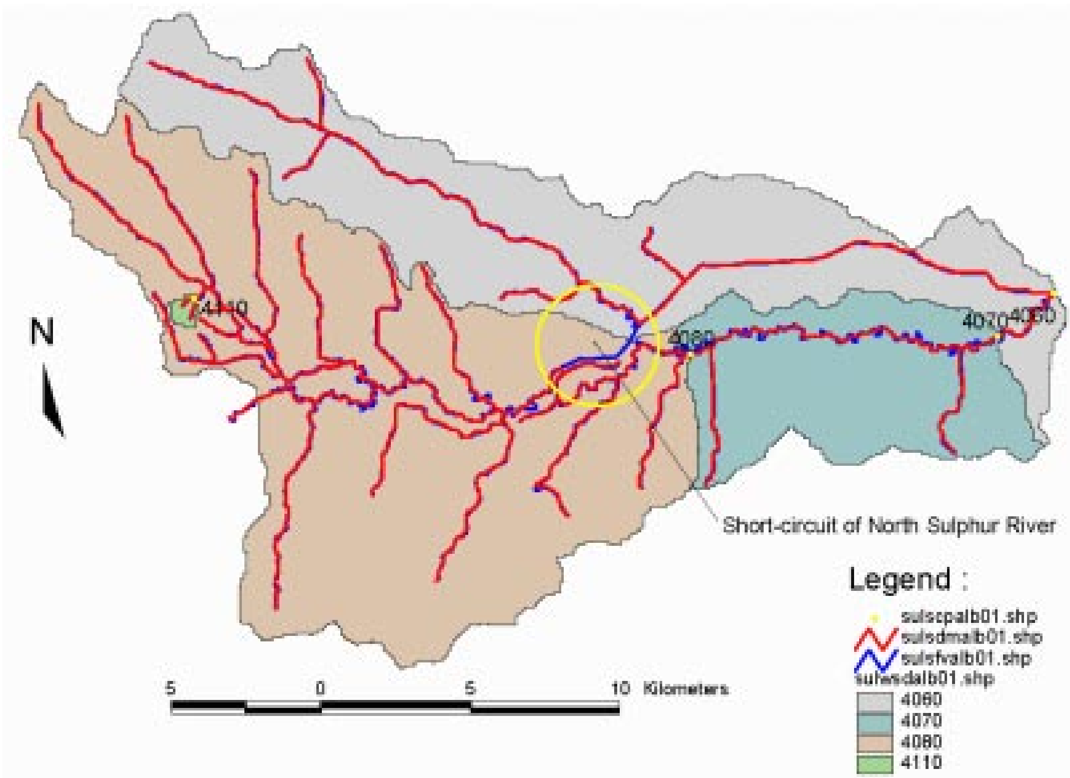


Figure 4.3 : Short-Circuit of North Sulphur River by 1:250,000 DEM

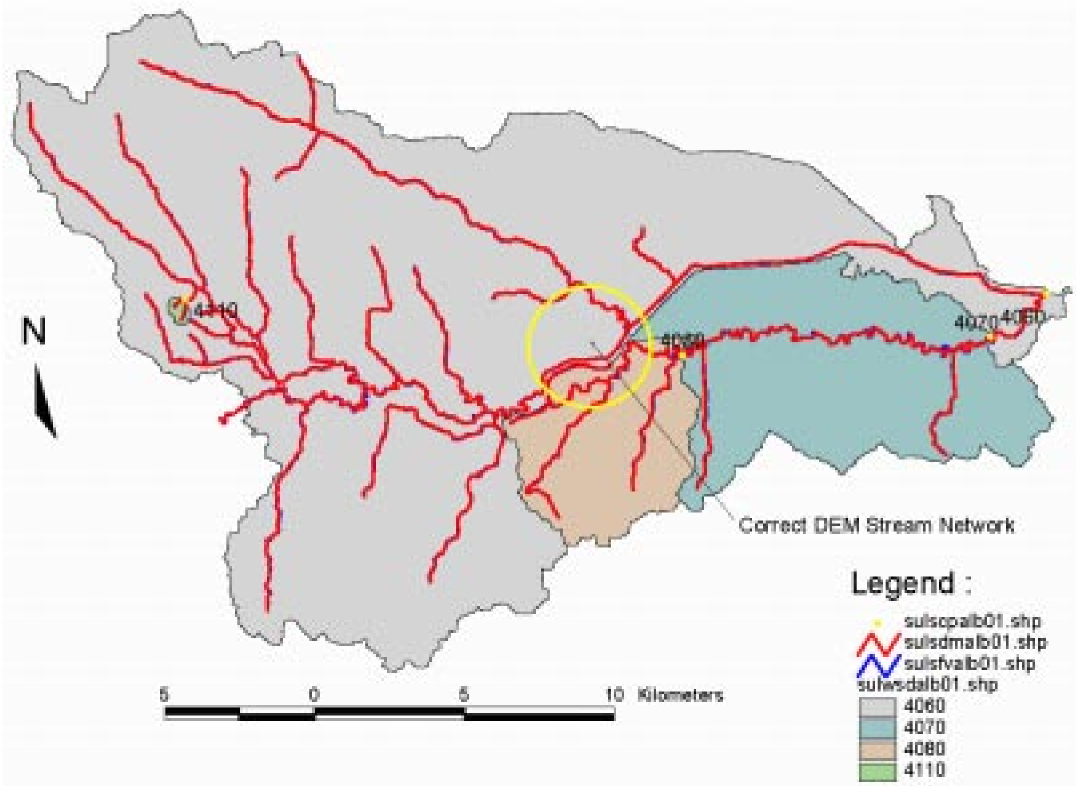


Figure 4.4 : 1:24,000 DEM Stream Network and Correct Drainage Areas

The drainage area differences reported in Table 4.3 are examined for a consistent bias. Throwing out the results for points 4070 and 4080, the differences are plotted in Figure 4.5, as the absolute difference, and in Figure 4.6, as the relative difference, with the 1:24,000 value as a baseline. While Figure 4.5 may seem to suggest a slight bias toward defining larger drainage areas with the 1:24,000 DEM, Figure 4.6 shows that this is largely insignificant. Of the 74 points examined, 43 adjustments are positive (reflecting a larger drainage area in the 1:24,000 DEM), and 31 are negative. The large outlying value of approximately +11% relative difference belongs to control point 2260. This is a very small watershed and the large relative difference in this case applies to an absolute difference of only 0.01 square miles.

Curve number adjustments are similar to those for drainage area. These are plotted in Figure 4.7. There appears to be no significant bias. The curve numbers obtained for the 1:24,000 DEM watersheds may be assumed to be more accurate, since they reflect the more accurate spatial location of the watershed boundaries.

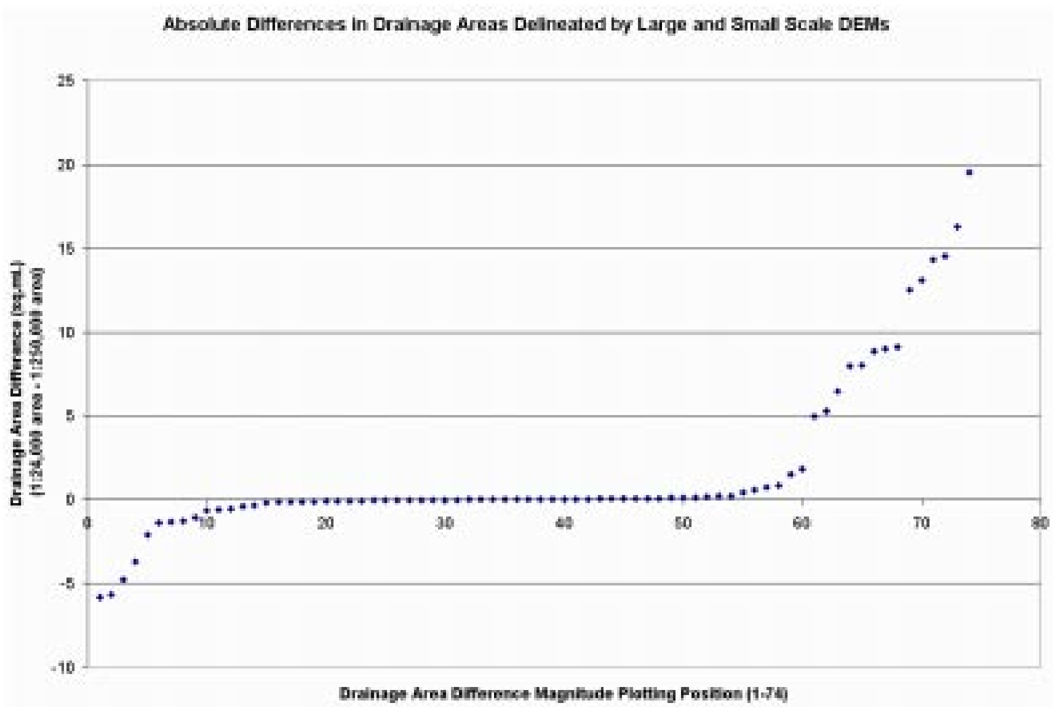


Figure 4.5 : Absolute Drainage Area Differences

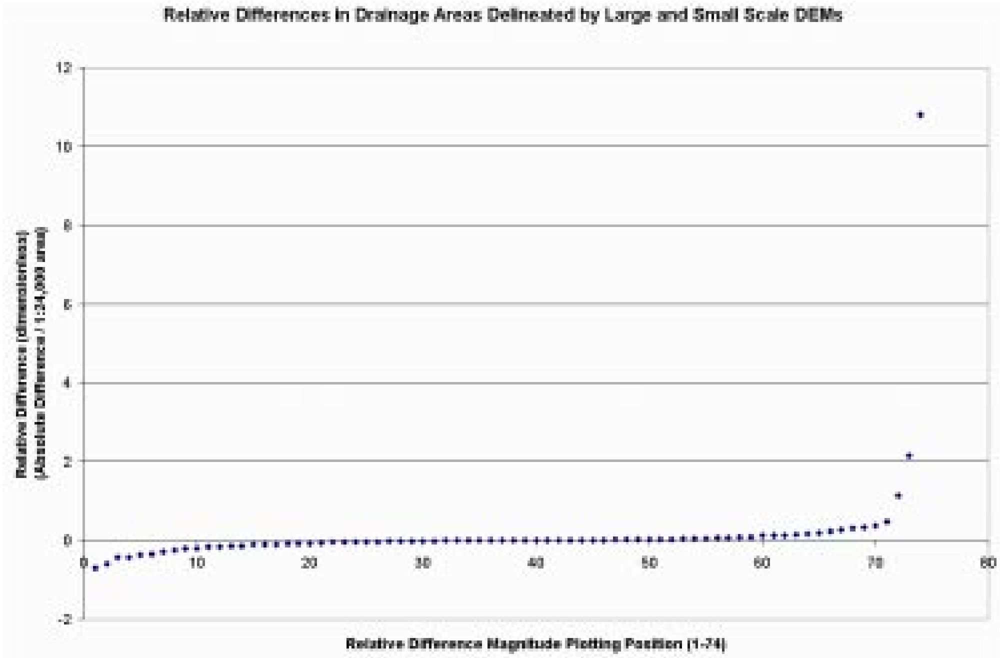


Figure 4.6 : Relative Differences in Drainage Areas

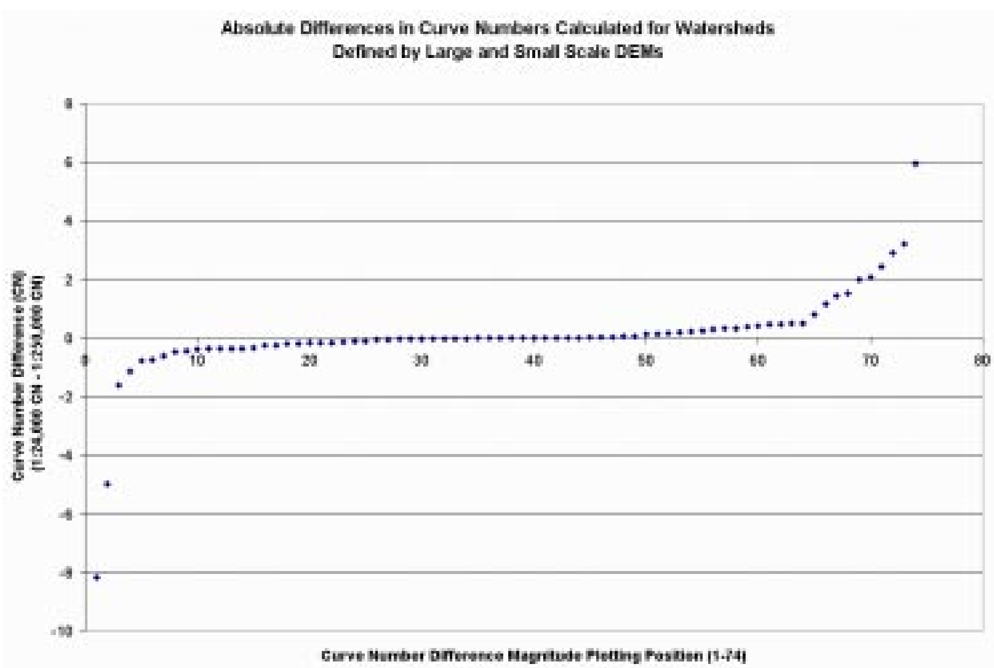


Figure 4.7 : Absolute Curve Number Differences

4.5 IMPROVED QUALITY CONTROL OF DRAINAGE AREAS

The potential for large errors in drainage areas as a result of DEM stream short-circuiting was belatedly realized when the 1:24,000 DEM data became available for comparison. To prevent this type of error, it is necessary to introduce another step into the quality control procedure presented in Section 3.11. This step consists of comparing the DEM stream network, ***sulsdmalb01.shp***, against the final vector stream network, ***sulsfvalb01.shp***, to identify any large short-circuits in the DEM stream network.

The quality control checks described in Section 3.11 are still performed. Drainage areas defined for stream gage control points are compared against the USGS reported drainage area values. Small watershed boundaries are compared against the DRG topography. For 1:250,000 scale DEM data, a threshold flow accumulation of 1,000 cells is used to define small watersheds. One grid cell of a 1:250,000 DEM, however, covers the area of approximately nine grid cells of a 1:24,000 DEM. It may be necessary to increase the threshold flow accumulation value defining small watersheds with 1:24,000 DEMs. On the other hand, the 1:24,000 DEM delineates watershed boundaries much more accurately. More experience in performing quality control of 1:24,000 watersheds in the project is necessary before a good estimate can be made of the proper threshold value.

To ensure the best quality control of drainage areas prepared with this project methodology, the following three step procedure is applied :

1. Visually compare the entire DEM stream network, ***sulsdmalb01.shp***, against the final vector stream network, ***sulsfvalb01.shp***. Identify any major short-circuits that will adversely affect the drainage area definition. To correct a short-circuit, the vector stream network must be edited to separate the stream arcs by more than the extent of one grid cell at the point where the short-circuit occurs. Then it is necessary to reprocess the DEM with the corrected vector stream network.
2. Compare the drainage area values obtained for stream gage control points with the values reported by the USGS. In the case of a large discrepancy, verify that the control point representing the gage is correctly located. Check that the latitude and longitude of the control point are correct, and check the relevant DRG to see if it shows a stream gage symbol in the vicinity.
3. Check the boundaries of small watersheds against the DRG topography. There are three possible sources of error in the DEM delineation of small watersheds. First, verify that the control point is located as precisely as possible, considering the resolution of the DEM grid cell size. Second, compare the vector stream network to the DRG. Small streams identified from the DRG but not represented in the vector stream network have not been burned into the DEM. In this case, it may be faster to simply manually digitize the watershed boundary for the control point in question. Otherwise, the missing

streams should be digitized and added to the vector stream network. The corrected vector stream network is then used to reprocess the DEM. Finally, the DEM may simply not be able to define topography at the same resolution as the 1:24,000 topographic map. In this case, a watershed boundary is manually digitized from the topographic map.

Chapter 5: Conclusions

A method has been presented for using geospatial data to determine flow distribution parameters at selected sites in a river basin. The parameters are used in the WRAP water availability model to distribute flows from gaged sites to ungaged sites. A digital elevation model is used to automatically delineate the watersheds for the model control points. A digital stream network is built from a combination of 1:100,000 and 1:24,000 scale hydrography. The stream network is used to condition the DEM to more accurately reflect the mapped hydrography. The curve number and precipitation parameters for each control point are read from existing curve number and precipitation grids that are averaged over the drainage areas. There were three objectives to this research : the creation of a geospatial database for a river basin, the extraction of the WRAP flow distribution parameters for each control point from the database, and the production of reliable digital watershed delineations.

A method of building a geospatial database for a river basin has been presented in Chapter two. The success criterion of this objective was the accomplishment and documentation of the procedures, such that they can be reproduced by other users in building similar databases of other river basins. This criterion has been met. Chapter two demonstrates that this task can be accomplished and documents the procedures for doing so. These procedures have been used to build geospatial databases for eight other river basins in Texas as part of the WAM project.

The second research objective has the same success criterion as the first. Flow distribution parameters for use in the WRAP model were successfully extracted from the database. The methodology for doing so is documented in Chapter three. This methodology has continued to develop while work has been ongoing on other river basins. The most recent changes to the methodology have been successfully applied to two other river basins.

The third research objective was the production of reliable watersheds from digital elevation data. In Chapter one it is noted that the success of this objective has to be subjectively judged. There is no absolute measure for determining the accuracy of these watershed boundaries. The best way found in this research to judge their accuracy is to visually compare them with topographic maps. The computed drainage area values for USGS stream gages can be compared against the USGS values, but agreement in the reported drainage area values does not prove that the watershed boundary is correctly located. Examination of the watershed boundaries produced from the 1:24,000 DEM of the Sulphur basin shows that they agree very well with the topography shown on DRGs. On this basis, this objective is stated as successfully completed.

The objective of producing reliable drainage areas cannot be stated as having been successfully completed where 1:250,000 DEM terrain data is used. In the course of this work, many sources of error have been identified in the production of small watersheds from 1:250,000 DEMs. In order to correctly delineate small watersheds from 1:250,000 DEMs, the DEM must be conditioned by a larger scale stream network.

A larger scale stream network was successfully produced with digitized 1:24,000 scale USGS topographic maps. The "blue line" method was used to identify small tributaries from these maps. The tributaries are manually digitized and added to the existing 1:100,000 scale RF3 stream network. Due to the time and effort required to manually digitize these tributaries, only those in the immediate vicinity of control points are added. While this work can be successfully performed manually, the publication of 1:24,000 scale hydrography for the entire state of Texas by TNRIS will considerably reduce the time and effort required to build a river basin database.

Even conditioning a 1:250,000 scale DEM with a 1:24,000 scale stream network does not guarantee correct delineation of small watersheds, due to the limited horizontal resolution of the elevation data. In the process of conditioning a 1:250,000 DEM with a much finer resolution stream network, another source for error is introduced in the form of stream short-circuiting. Errors in the delineation of small watersheds can be corrected by manually digitizing the watershed boundaries from the DRG topographic maps. Short-circuiting, however, can introduce large errors into any size watershed. Finally, it becomes apparent that only a rigorous quality control procedure will provide acceptable drainage area results from 1:250,000 scale DEM data. All results from the DEM must be checked. The DEM stream network must be compared to the original vector stream network to identify any major short-circuiting errors, and ideally all watershed boundaries should be checked.

This is a very time-consuming process and involves so much user-input that mistakes are hard to avoid. Streams must be manually digitized from 1:24,000 scale topographic maps, and many small watershed boundaries must be manually digitized as well. This is especially true of large river basins that may spread across more than a hundred quad sheets and contain several hundred WRAP control points. As errors are found, the entire basin must be re-processed and put through the quality control process again. It is not unlikely that a large river basin would have to go through several iterations of processing and checking the results before they could be accepted.

The need to delineate small watersheds in the WAM project and the effort required to accurately do this with the small scale DEMs indicates that 1:24,000 scale DEMs should be used in processing all of the river basins. The use of 1:24,000 DEMs does add some additional processing considerations to the methodology. File sizes and processing times will be considerably increased. Larger river basins may have to be subdivided into sub-basins to even be able to process the grids. The use of 1:24,000 scale DEM data, however, is much cleaner and provides greater confidence in the parameter results. Quality control is still necessary, but, with the fine resolution of the 1:24,000 DEMs watershed boundaries, errors will more likely result from the exact location of the control point, which is more easily corrected. Stream short-circuiting is much less common. No major short circuits are observed in the 1:24,000 DEM stream network of the Sulphur basin. The high terrain resolution of the 1:24,000 DEM even suggests that the necessity of the vector stream burning process should be studied. The 1:24,000 DEM data may accurately reflect mapped hydrography without the conditioning process.

While drainage areas can be quality controlled against the DRG topography, it is more difficult to judge the reliability of the precipitation and curve number values for each watershed. Two factors can be considered when assessing the reliability of the resulting precipitation and curve number values: the quality and the resolution of the source data. The quality of the data is determined by the method of its development and its review and acceptance by experts. The resolution of the data is important when considering the values produced for small watersheds.

The precipitation data comes from a thoroughly reviewed and accepted source, the Oregon State University PRISM climate mapping project. The original data has a grid cell size of 250 meters. This is a very coarse resolution to apply to small watersheds, but, by nature, an areal coverage of precipitation data must be coarse in resolution, because precipitation must be interpolated from a relatively few point gages. The precipitation adjustment in the flow distribution calculation is a small one, and the parameter is of minor importance compared to drainage area and curve number. While the values computed for small watersheds may not be the most accurate, the overall precision of the data is satisfactory for the purpose of the parameter. In the modified NRCS method of flow distribution in the WRAP model, the parameter is used to adjust long term precipitation between sites that are located a relatively long distance from one another.

The curve number data is more questionable. The original curve number grid was obtained from the Blacklands Research Center. It is at a map scale of 1:250,000. Several of the curve number values produced for small watersheds in the project have been questioned by the basin contractors. The results are faithful to the curve number grid, but the resolution of the curve number grid may simply be too coarse to expect accurate curve number parameters for small watersheds. The curve number values will have to be accepted as is, until finer resolution sources of land use and soil data become widely available. If curve number values are deemed to be unacceptable, then flows in the basin may simply be distributed based on drainage area ratios.

The method of determining hydrological parameters from geospatial data presented in this research was designed specifically to support the water availability modeling requirements of the TNRCC. The method could also be applied to support any hydrological model requiring input parameters at points along a stream network. The specific procedures and code developed in this work can be relatively easily generalized to work with any geospatial source data sets. The user should always keep in mind that the accuracy of the resulting parameters depends on the quality of the source data.

Appendix A : Exercise 1

A.1 Exercise Table of Contents

A.2 Introduction

The Water Availability Modeling (WAM) project was begun by TNRCC in 1998. TNRCC was directed to undertake this project by the Texas legislature when Texas Senate Bill 1 was passed in 1997. Senate Bill 1 was the legislature's response to the need for better water planning throughout the state, which became evident in the drought of 1996. The WAM project will produce water availability models for 22 of the 23 major river basins in Texas, with the Rio Grande river being modeled as a separate project. TNRCC defines water availabiliy models as "computer programs that calculate the amount of water in a river basin using hydrologic principles and actual measurements taken at stream gages" (TNRCC, 1999).

TNRCC selected the Texas A&M University's Water Rights Analysis Package (WRAP) model to serve as the actual model used in analysing each basin. WRAP calculates regulated stream flows at selected points in a basin based on an input sequence of historical naturalized stream flows. Naturalized stream flows are flows with the effects of man removed. They are calculated from historical records by adding and subtracting records of the quantities of water diverted, stored, and returned along the river. In some cases, even the effects of land use changes on the rainfall-runoff relationship may be calculated and included. Several years of naturalized stream flow data are needed in the WAM project in order to be able to judge the average availability of water over long terms. Typically, this information is only available at a few sites in a river basin : USGS stream gages and at older reservoirs. To prepare an input sequence of naturalized stream flows at other points in the basin, flows are distributed from these known flow locations to the unknown flow locations.

There are several methods for distributing stream flows from known to unknown flow locations. Typically, stream flows are distributed based on the drainage area ratio of the unknown to known flow points.

$$Q_{ungaged} = Q_{gage}\left(\frac{A_{ungaged}}{A_{gaged}}\right) \qquad (A.1)$$

In the WAM project an effort has been made to include other watershed characteristics in the flow distribution calculations. The NRCS curve number equation was developed to estimate the storm runoff from a watershed based on an input precipitation amount and a description of the watershed's tendency to abstract rainfal given by the curve number.

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \quad where \quad S = \frac{1{,}000}{CN} - 10 \qquad (A.2)$$

For the WAM project, the curve number equation is applied to average monthly stream flows. Equation 2 is inverted to obtain the monthly precipitation from an input monthly stream flow. This monthly precipitation is then distributed to the drainage area of the unknown flow location. The ratio of mean annual precipitation values, M, for the two drainage areas may be used to adjust the distributed monthly precipitation value.

$$adjusted\ P_{ungaged} = P_{gage}\left(\frac{M_{ungaged}}{M_{gage}}\right) \qquad (A.3)$$

In the WRAP model, control points are used to identify location for which stream flows are to be calculated. There may be hundreds of control points in a river basin model. To calculate the drainage area, curve number, and mean annual precipitation of each drainage area by hand would be very tedious. Fortunately, geospatial data sets exist for each of these parameters, allowing them to be automatically calculated using GIS. This exercise presents a method for calculating these parameters that has been developed for the WAM project.

A.3 GOALS OF THE EXERCISE

The intent of this exercise is to familiarize you with the methodology used in the WAM project to calculate flow distribution parameters from geospatial data sources for the control points in a WRAP model. By the end of this exercise you will be able to :

- Use the WRAP Parameters ArcView project tools to develop the WRAP flow distribution parameters from a geospatial river basin database

- Use Digital Raster Graphics (DRG) topographic maps as a reference in working with digital hydrography.

A.4 GEOSPATIAL RIVER BASIN DATABASE

The first step in preparing flow distribution parameters for use in the WRAP model is to build a geospatial database for the river basin. For each river basin modeled in the WAM project, a database consisting of twelve components is compiled. These components are :

- ***River basin boundary***. A polygon of the basin drainage area.
- ***DRG files***. TIFF image files of 1:24,000 USGS quadrangle topographic maps.
- ***Digital elevation model (DEM)***. Elevation grid used to automatically delineate drainage areas.
- ***River Reach Files (RF3)***. 1:100,000 scale coverage of water features digitized from aerial photography.
- ***USGS open water centerlines***. USGS digitized centerlines through open water features.
- ***Base stream network***. RF3 with open water feature boundaries deleted and USGS centerlines added in their place.
- ***USGS gage locations***. Point locations of USGS stream gages.
- ***Water right database record locations***. Point locations of entries in TNRCCs master water rights database.

- ***TNRCC water right diversion points***. Actual diversion and return flow points associated with individual water rights.
- ***Curve number grid***. Gridded curve number data.
- ***Mean annual precipitation grid***. Gridded estimate of mean annual precipitation trends.
- ***Texas water quality segments***. TNRCC identified water quality segments and segment boundaries.

A.5 WRAP PARAMETERS INTERFACE

The WRAP Parameters interface is an ArcView 3.1 project file with a set of Avenue scripts designed specifically for the task of extracting the WRAP flow distribution parameters from geospatial data sets. The scripts are organized into two menus, "WRAP Parameters" and "WRAP Tools," and a set of buttons on the toolbar.

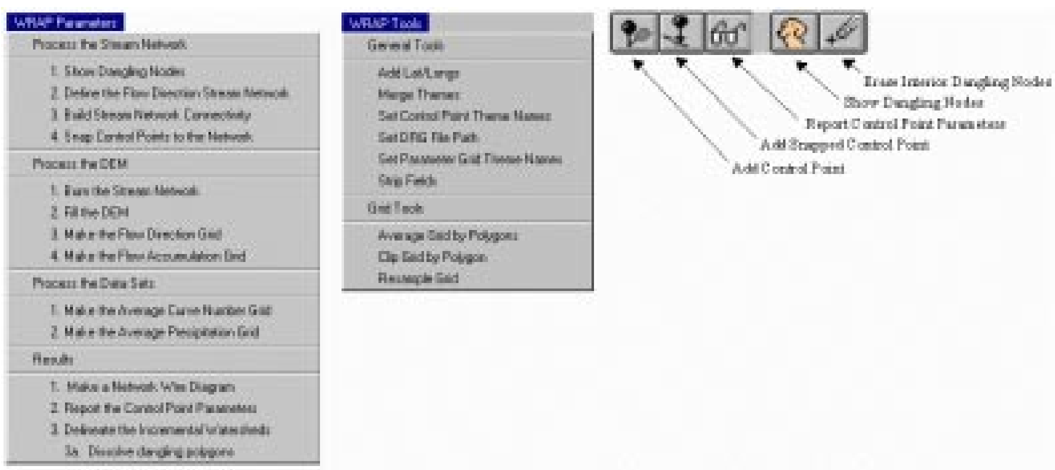


Figure A.1 : WRAP Parameters Interface

A.6 EXERCISE STUDY AREA AND DATA

This exercise uses a study area within the Sulphur River basin. The Sulphur River is a tributary of the Red River located in Northeast Texas. This exercise considers the watershed of the Middle and South Sulphur Rivers. These two branches join in the vicinity of Cooper, Texas. Figure A.2 shows this area. The red points are the eight WRAP model control points in the study area. The large body of water is Jim Chapman Lake.

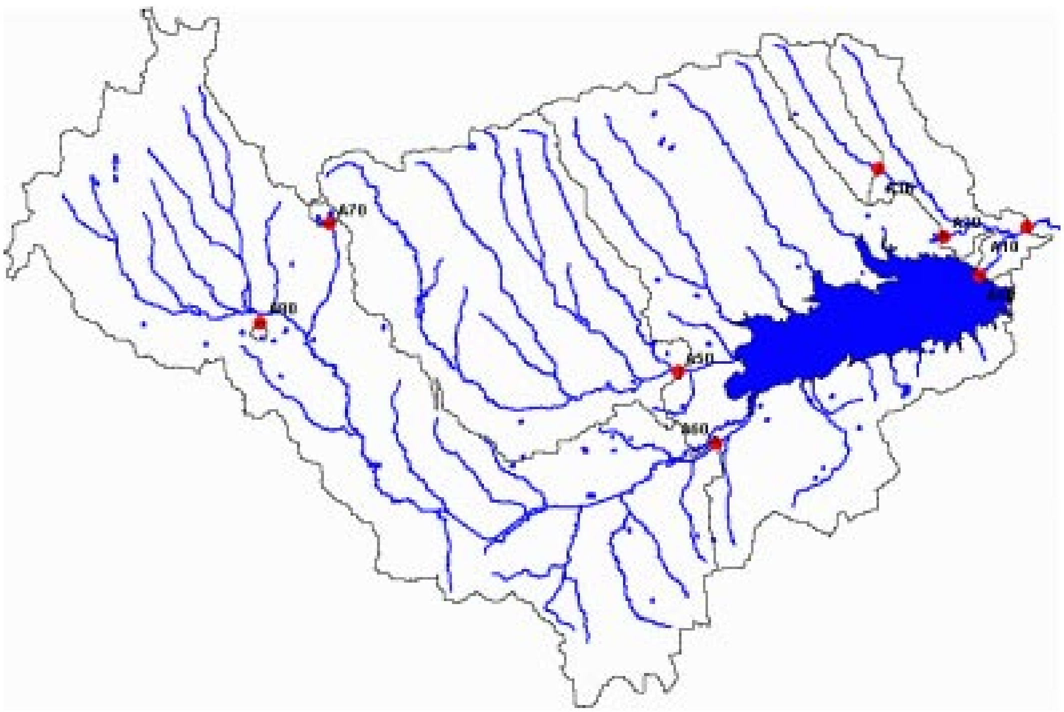


Figure A.2 : Exercise Study Area

A smaller database has been extracted from the original Sulphur River Geospatial Database for use in this exercise. The coverages needed for this exercise are :

- ***Texmeshutm15.shp***. A mesh of 7.5 minute quadrangles covering the state of Texas.
- ***Chapman.shp***. A shapefile showing Lake Jim Chapman included for reference.

- ***Exrdemalb***. 1:24,000 scale DEM for the exercise study area.
- ***Exrrfiutm.shp***. The RF3 coverage contained within the study area.
- ***Exrrfeutm.shp***. The RF3 coverage surrounding the study area.
- ***Exrctlutm.shp***. USGS open water centerlines within the study area.
- ***Exrsglutm.shp***. USGS stream gages in the vicinity of the study area.
- ***Exrwruutm.shp***. TNRCC water right records within the study area.
- ***Exrcngalb***. Curve number grid for the study area.
- ***Exrpcpalb***. PRISM mean annual precipitation grid for the study area.
- **DRG files.** TIFF image files of scanned USGS topographic maps.

Also included in the exercise folder are the WRAP Parameters project file, "wrap1117.apr," and the text files used in projecting coverages between Albers and UTM projections, "albtoutm.txt" and "utmtoalb.txt". This data is available for download in a WinZip archive at :

http://www.ce.utexas.edu/prof/maidment/grad/hudgens/research.html

This data is also available on the companion CD to this thesis, "CD1," in the folder "exercise1." The DRG files for the exercise are contained on the companion CD, "CD2."

A.7 METHODOLOGY

A.7.1 Using DRGs

Digital Raster Graphics (DRGs) are scanned USGS 1:24,000 scale topographic maps. They provide a frame of reference for viewing other coverages in the database and they have relatively detailed mapped hydrography. Each topographic map covers a 7.5 minute latitude by longitude quadrangle. Each quadrangle map sheet has a name, but the USGS uses a more systematic method of locating each quad. Each quadrangle is identified by an alphanumeric code, combining the numerals of the latitude and longitude of the lower right corner of the 1°x1° box with an alphabetical row and numerical column identifier for the individual quad.

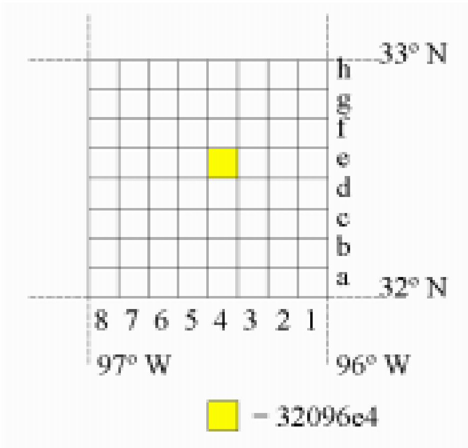


Figure A.3 : USGS Quadrangle Naming Convention

To view the DRG files, first add ***texmeshutm15.shp*** to the View. The DRG files can be added as individual image files, but since you'll need to work with several files the project file contains a script to make this work easier. The script "wrap.addtopo" is embedded in the project file. You'll use it to make a hot link between the ***texmeshutm15.shp*** quadrangles and the individual DRG files. Make ***texmeshutm15.shp*** the active theme. Now, under "Theme/Properties", click on the "Hot Link" picture. In the selection window that comes up, set the field to "Code," the predefined action to "Link to User Script," and the script to "wrap.addtopo." Now when ***texmesutm15.shp*** is the active theme you'll see the Hot Link tool become available for use. Before you can use the tool, however, you have to tell the script the directory file path to the DRG files. In the WRAP Tools menu, select the "Set DRG File Path" item and enter the file path to the DRG files. Add the theme ***exrbasutm.shp*** and zoom the display to the basin extent. Now, click on the Hot Link tool, and use the lightning bolt to select one of the quadrangle polygons in the study area. The "wrap.addtopo" script automatically adds the image theme and zooms the display to the selected quadrangle.

Each DRG file includes the entire map image including the map collar. To make it easier to view multiple DRGs simultaneously, the "wrap.addtopo" script only displays a rectangle roughly conforming to the quadrangle boundary. If you want to know more about the topographic maps, you can add one of the DRG files to the view with the regular Add Theme tool and zoom into the map collar to read the map sheet information.

A.7.2 Assembling the Control Points

Before beginning any work towards generating flow distribution parameters you need to know where the specific points of interest, the model control points, in the basin are. In the WAM project, the contractor that models the basin decides where the control points are located. Typically, these will consist of stream gages, water right diversions points, return flow points, and water quality segment boundaries. Some of these points already exist as geospatial data. Stream gages are located in the original river basin database. Add the point theme, ***exrsglutm.shp*** to the view. The water right diversion points and return flow points are usually located by TNRCC and supplied in a point shapefile, in this case ***exrwruutm.shp***. Add this theme to the view. Some control points may not be in these shapefiles, however. If the basin modeler decides to place a control point at a site that's not already located, they can indicate the point on a topographic map marking the exact location of the control point.

The eight control points used in the original WRAP model of the Sulphur River basin in this sub-watershed were identified as A10-A80. The WRAP Parameters scripts only recognize integers as control point identifiers so you'll identify these points as 6010-6080. Before entering the control points, you'll need to set the control point shapefile name using the WRAP Tools menu item, "Set Control Point Point Theme Names." Set the control point shapefile name to ***exrfcputm.shp***. Now, using the "Add Control Point" tool from the WRAP Parameters toolbar, enter a control point at each location identified in Table A.1.

CP ID	**Model CP**	**Type**	**Location**
6010	A10	Stream gage	USGS gage # 7342500
6020	A20	Diversion point	Water right 4800
6030	A30	Diversion point	Water right 4395
6040	A40	Diversion point	Water rights 4797, 4798, 4799
6050	A50	Return flow	See map in image file "cp6050.gif"
6060	A60	Return flow	See map in image file "cp6060.gif"
6070	A70	Diversion point	Water right 4795. See map in image file "cp6070.gif"
6080	A80	Diversion point	Water right 4796

Table A.1 : Exercise Control Points

A.7.3 Building the Stream Network

Next, you'll build a digital stream network representing the channel hydrology in the basin. This stream network serves two purposes. First, it can be used to condition the DEM to better reflect the mapped hydrography given in the RF3 coverages. Secondly, it can be used to establish connectivity among points in the basin. To accomplish these tasks, the stream network must be defined as a single-line flow path with each channel segment flowing into only one downstream segment.

Three types of corrections must be made to the existing RF3 stream coverage. First, open water features are removed from the RF3 coverage, and USGS centerlines are inserted in their place. Also, braided channels are reduced to one channel segment. Second, smaller tributaries are added to the stream network. RF3 is defined at a map scale of 1:100,000. Smaller tributaries can be identified from the 1:24,000 scale DRGs. Adding these tributaries helps to ensure the most accurate delineation of drainage areas by the DEM. Adding all the blue lines from every DRG in a river basin would be an imposing undertaking, so this effort is focused on the immediate vicinity of each control point. Third, the topology of the line theme is corrected by closing any gaps between connecting arcs and deleting any dangling nodes in the interior of the network.

First, you'll remove the open water features from RF3 and add the USGS centerlines. Add the themes ***exrrfiutm.shp*** and ***exrctlutm.shp*** to the view. Make ***exrrfiutm.shp*** the active theme and click on the Theme Query tool. In the query dialog that follows, query the "Reachtype" field for the attributes "R","S", and

“T.” These codes identify “regular,” “start,” and “terminal” reaches in RF3. In this exercise, there are no terminal reaches in the basin, so the “T” attribute will not be listed. Use the “Theme/Convert to Shapefile” menu item to save these selected reaches as a new theme, ***exrstputm.shp***. Now, use the WRAP Tools menu item, “Merge Themes” to merge ***exrstputm*** with ***exrctlutm.shp***. Name the result, ***exrswvutm.shp***. Now you have a working version of the stream network to begin editing. Copy ***exrrfeutm.shp*** to a new shapefile called ***exrswxutm.shp***. Now you can delete the RF3 attributes from each of the stream network working themes. Use the WRAP Tools menu item “Strip Fields.” This function will delete all but the selected fields, making the file sizes smaller and the themes easier to edit. You need only retain “Shape” and one other identification field.

You may notice that RF3 does not show Jim Chapman Lake. This reservoir only began impounding water in 1991. Apparently the sources used in creating RF3 pre-date this time. This is an important feature of the study area. It is the location of the majority of water storage and use in the watershed. The shapefile, ***chapman.shp***, is included with the exercise data so you can reference the location of the reservoir.

There are several ways to go about editing the stream network in an organized manner. A suggestion is to work one quadrangle at a time, keeping track of which quadrangles have been finished, and, most importantly, **saving your edits** after each. Several ArcView tools are used in this process. Figures A.4 and A.5, below, reference the standard ArcView tools and the WRAP Parameters project tools used in this work.

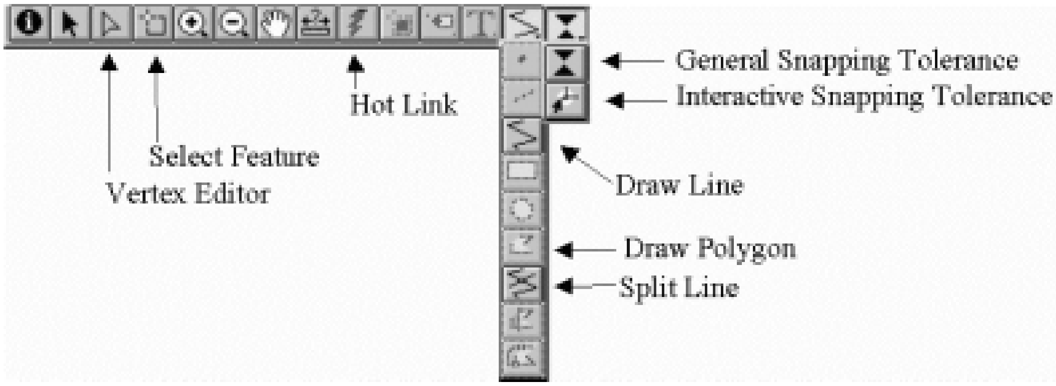


Figure A.4 : ArcView Editing Tools

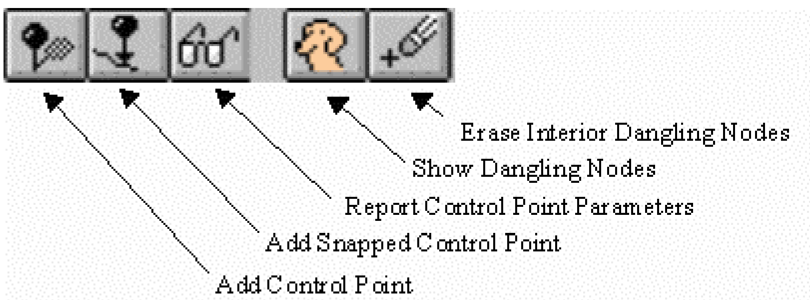


Figure A.5 : WRAP Parameters Tools

First, make ***exrswvutm.shp*** the active theme, and, under "Theme/Properties", click on the Editing properties icon. In the editing properties dialog box turn both the general and interactive snapping features on by checking the boxes next to them. Do the same for ***exrrfeutm.shp***. Notice that the "Snap Tolerance" tool now appears in the view window. Before each edit, be sure you use this tool to set the snapping tolerance to an appropriate extent. Now, for each quadrangle, go through the following steps :

1. With ***exrswvutm.shp*** the active theme, use the "Show Dangling Nodes" tool or menu function to identify any disconnects in the stream network. Zoom in and connect the endpoints using the "Vertex Editor" tool.
2. Identify any braided channels. Reduce each braided channel system to a single streamline. Using the DRGs as a reference, identify a single path through the braided channel system and delete the other arcs.
3. Now, for each control point in the quadrangle, zoom into the immediate vicinity. Use the DRG to identify any tributaries not already in the RF3 coverage. Add all streams surrounding the control point. This will ensure accurate definition of the control point's drainage area. Figure A.6 shows an example of this for one control point. The highlighted arcs have all been added. Where a point lies near the basin boundary, you may also need to add streams that flow away from the basin drainage area. You can do this by adding the streams to the ***exrrfeutm.shp*** coverage.

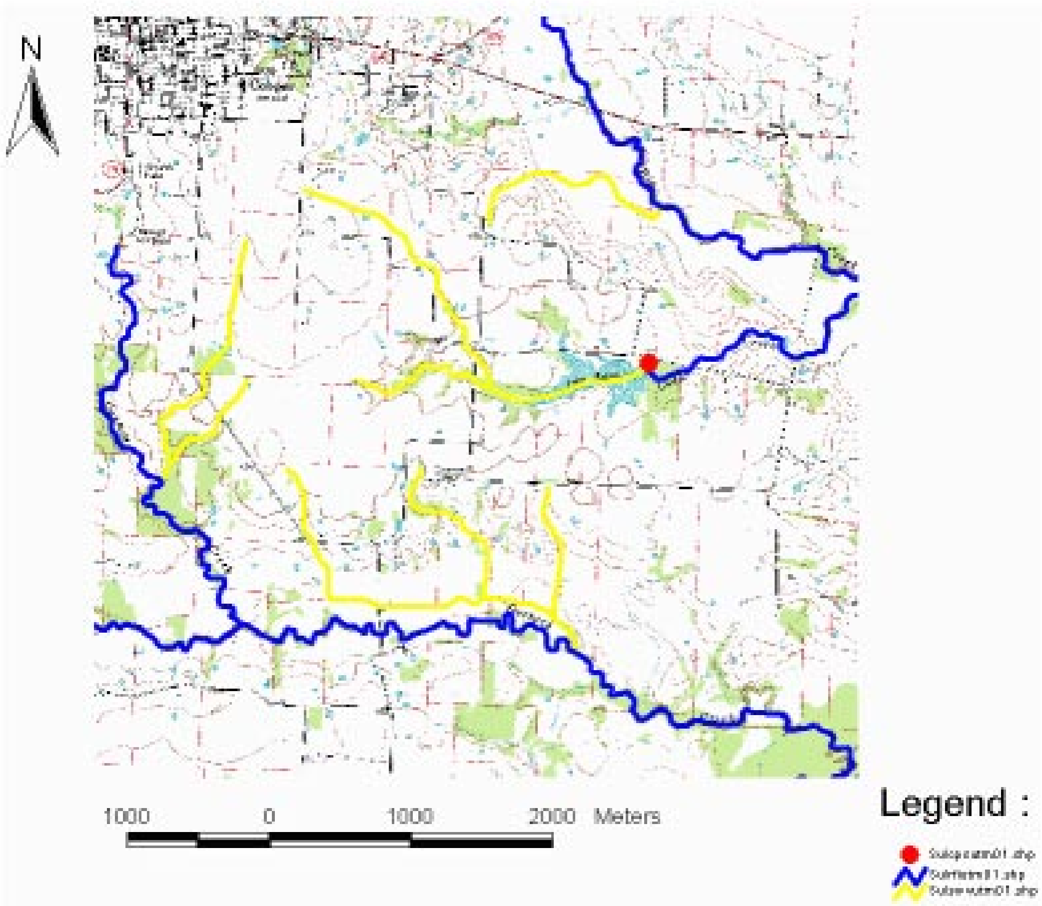


Figure A.6 : Streams Added to the Base Network

First, set both the general and interactive snapping tolerances to an appropriate extent. An appropriate extent is a radius smaller than the distance between adjacent vertices in the RF3 line theme. Now, use the “Draw Line” tool to digitize the stream. The general and interactive snapping features should be used as necessary to ensure that the added line’s endpoints coincide with existing line vertices and endpoints.

4. As you are adding tributaries, you must correct the topology of the line theme. A line theme has correct topology when each node of a line connects to a node of a different line. Nodes that do not connect to other nodes are dangling nodes. In a stream network, headwater reaches will have dangling nodes by definition. These are not corrected. As you add tributaries, however, you create dangling nodes in the interior of the network. Each time you snap the endpoint of an added tributary to the middle of an existing stream arc, a dangling node is created, since the snapped endpoint is not actually connected to another **node** (it is snapped to an interior vertex.) Correct these interior dangling nodes with the "Erase Interior Dangling Nodes" tool.
5. Look closely for any large loops and parallel connections in the RF3 channel system. Dead channels and digitizing errors may create large loops in the channel network. These should be removed so that the resulting network has unique downstream flow paths.
6. Finally, use the "Show Dangling Nodes" tool to double check that you have not added any interior dangling nodes within the quadrangle.

When you have finished editing the stream network save it as ***exrsfvutm.shp***. Also save the edited exterior stream network as ***exrsfxutm.shp***.

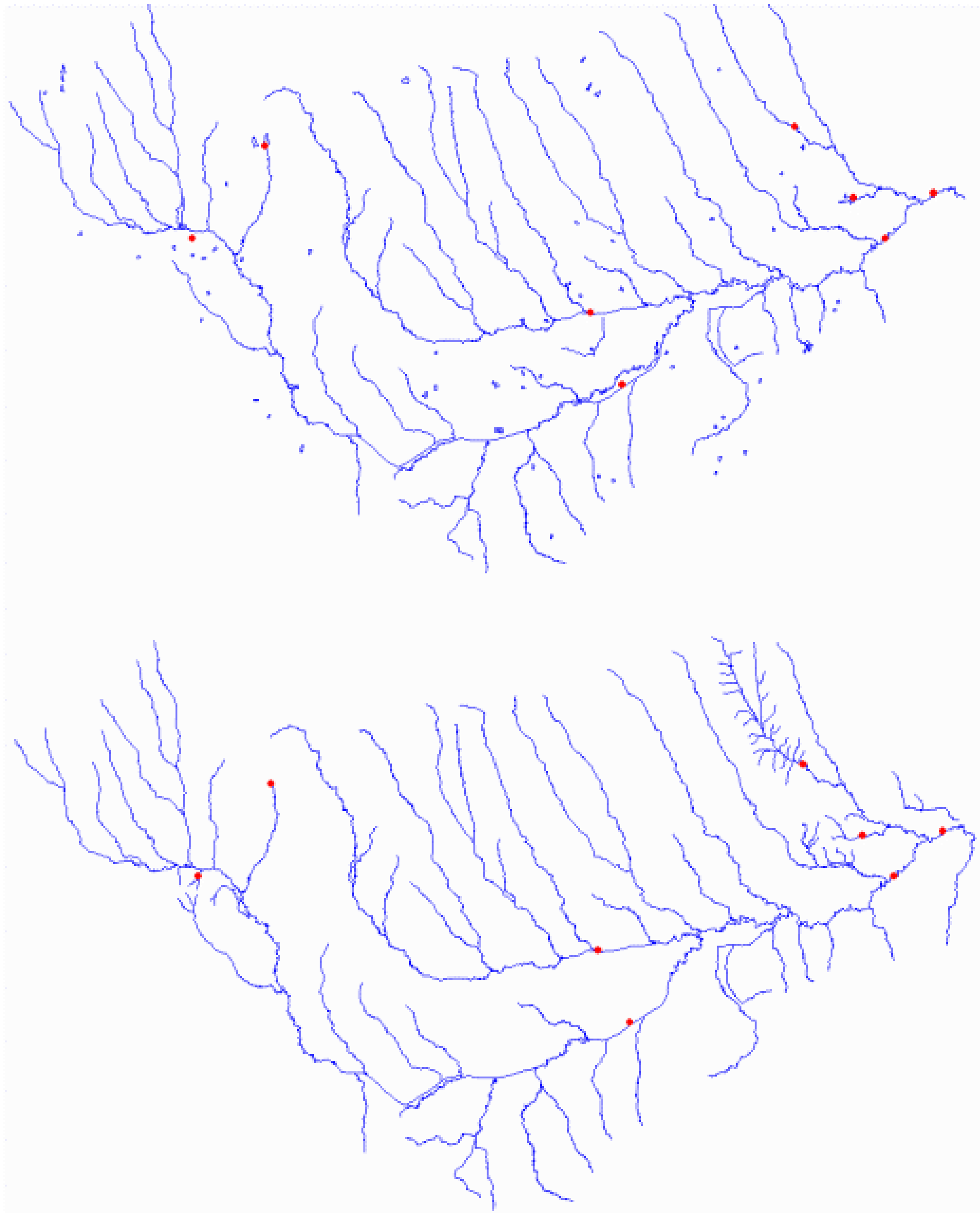


Figure A.7 : Stream Network, Before Editing (above) and After (below)

A.7.4 Processing the DEM

The DEM is in the TSMS Albers projection. You'll need to project the themes that you've created so far to this projection. Use the projection file "utmtoalb.txt" to project ***exrfcputm.shp***, ***exrsfvutm.shp***, and ***exrsfxutm.shp***.

Arc : **shapearc *exrfcputm exrfcputm***
Arc : **shapearc *exrsfvutm exrsfvutm***
Arc : **shapearc *exrsfxutm exrsfxutm***
Arc : **project cover *exrfcputm exrfcpalb* utmtoalb.txt**
Arc : **project cover *exrsfvutm exrsfvalb* utmtoalb.txt**
Arc : **project cover *exrsfxutm exrsfxalb* utmtoalb.txt**
Arc : **copy *exrfcpalb tmp1***
Arc : **copy *exrsfvalb tmp2***
Arc : **copy *exrsfxalb tmp3***
Arc : **dropitem *tmp2.aat tmp2.aat***
Enter the 1st item : **fnode_**
Enter the 2nd item : **tnode_**
Enter the 3rd item : **lpoly_**
Enter the 4th item : **rpoly_**
Enter the 5th item : **end**
Arc : **dropitem *tmp3.aat tmp3.aat***
Enter the 1st item : **fnode_**
Enter the 2nd item : **tnode_**
Enter the 3rd item : **lpoly_**
Enter the 4th item : **rpoly_**
Enter the 5th item : **end**
Arc : **arcshape *tmp1* point *tmp1***
Arc : **arcshape *tmp2* line *tmp2***
Arc : **arcshape *tmp3* line *tmp3***
Arc : **kill *tmp1* all**
Arc : **kill *tmp2* all**
Arc : **kill *tmp3* all**
ArcView : **In View menu "File," click on "Manage Data Sources"**
ArcView : **Rename *tmp1.shp* as *exrfcpalb.shp***
ArcView : **Rename *tmp2.shp* as *exrsfvalb.shp***
ArcView : **Rename *tmp3.shp* as *exrsfxalb.shp***

A.7.4.1 Burning the DEM with the Vector Stream Network

In the WAM project, some control points represent very small drainage areas. To ensure that the flow distribution to these points is the best possible estimate, the drainage area must be defined as accurately as possible. DEMs sample elevation data at regularly spaced points. A 1:250,000 scale DEM samples elevations at about every 90 meters on the ground, and a 1:24,000 scale DEM at about every 30 meters. It is possible that small drainage features will not be correctly represented within this mesh of terrain data. 1:250,000 scale DEMs especially tend to over or under-estimate small drainage areas, particularly in flat, coastal areas.

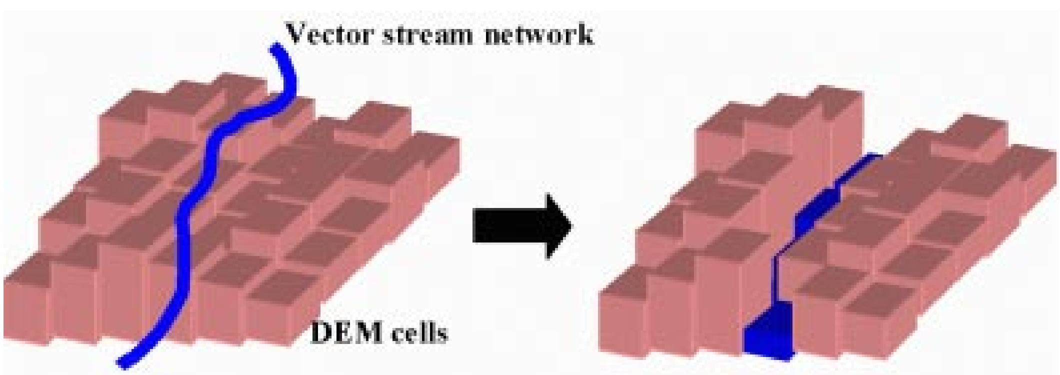


Figure A.8: Conceptual View of the Stream Burning Process

To ensure the most accurate drainage area delineation, the combined exterior and interior stream networks are burned into the DEM as shown in Figure A.5. In processing a basin for the WAM project, the exterior stream network would first be clipped to an extent just greater than the DEM. Since this study area is relatively small, you'll skip this step. Use the WRAP Tools menu item, "Merge Themes," to merge ***exrsfvalb.shp*** and ***exrsfxalb.shp***. Name the output shapefile ***exrsbnalb.shp***.

Burn the stream network, ***exrsbnalb.shp***, into the DEM using the WRAP Parameters menu item, "Burn Stream Network." First set the "Analysis/Properties." Set both the analysis extent and cell size to "same as ***exrdemalb***." The output grid, ***burndem***, is a temporary grid. You need to make of copy of this grid and save it as a permanent grid before you delete the theme from the view, otherwise it will be lost. Use the "Copy" option under File/Manage Data Sources to make a copy named ***exrbdmalb***.

A.7.4.2 Fill, Flow Direction, and Flow Accumulation

Process the burned DEM with the fill, flow direction, and flow accumulation functions. These are all included in the WRAP Parameters menu. Again, the resulting grids, ***filldem, fdr,*** and ***fac*** are temporary grids. Copy them into permanent grids : ***exrfdmalb***, ***exrfdralb***, and ***exrfacalb*** respectively.

A.7.5 Creating the DEM Stream Network

Implicit in the flow direction and flow accumulation grids of the DEM is a stream network based on the Eight Direction Pour Point model. Typically, this stream network is explicitly defined as a grid, by applying a threshold drainage value to the flow accumulation grid. In this project, you will define the DEM stream network as a line theme, created by tracing the flow direction grid from each headwater node of the vector stream network, ***exrsfvalb.shp***. Use the WRAP Parameters menu item, "Define Flow Direction Stream Network." Two temporary shapefiles are created in the working directory by this function, ***headwaters.shp*** and ***centered.shp***. These may be deleted. The resulting shapefile ***fdrstrmnet.shp*** has one polyline extending from each headwater node to the basin outlet. Now you need to segment these overlapping lines into the individual stream segments. You can do this in ArcInfo using the "clean" command.

You must be careful to use the smallest possible fuzzy tolerance when cleaning the coverage, so that no unwanted changes are made. To do this, enter a very small fuzzy tolerance, such as 0.001, and the clean function will default to the minimum tolerance allowed by the coverage. Take a look at this default value. It should be smaller than the grid cell size of the DEM by at least an order of magnitude. If it approaches the DEM cell size, the stream segment vertices may actually be moved by "clean," creating unwanted modifications in the network.

Arc : **shapearc *fdrstrmnet temp***
Arc : **clean *temp temp* # 0.001 line**
Arc : **build *temp* line**
Arc : **arcshape *temp* line *temp***
Arc : **kill *temp* all**
ArcView : **In View menu "File," click on "Manage Data Sources"**
ArcView : **Rename *temp.shp* as *exrsdmalb.shp***

Next, run the WRAP Parameters menu function "Build Stream Network Connectivity" on the DEM stream network, ***exrsdmalb.shp***. This function assigns a unique arc ID to each stream segment, then attributes each segment with the arc ID of the next downstream segment. Now you have a true stream network : each arc points downstream and connects to only one downstream arc, with each arc knowing the identity of that downstream arc.

A.7.6 Attaching Control Points to the Stream Network

The next step is to attach the control points to the DEM stream network. The WRAP Parameters menu function, “Snap Control Points,” will do this for the control point coverage. First, set the name of the snapped control point coverage to ***exrscpalb*** using the WRAP Tools menu item, “Set Control Point Theme Names.” There are two tricks to using the snap control points function. First, when the script executes, each control point finds the nearest arc to itself. The Avenue command that does this works on the basis of screen pixel distance. It is only able to find arcs within a radius of three screen pixels from the point. To make sure each point is able to find an arc, first zoom the display to the extent of the stream network theme. Then click on the “Zoom Out” tool twice. Experience with the project so far has shown that, at this view extent, each control point will be able to find an arc. The script will ask you for a snapping tolerance. Set this to 100 meters.

Second, after snapping the points you should review the snapped coverage to make sure that they are all correctly located. Points that are near stream junctions are very prone to being snapped incorrectly. The DEM stream network sometimes deviates from the original vector network representation in the vicinity of stream junctions, and the closest arc in the DEM stream network may not be the same as the arc that the control point was originally placed next to. Compare the original stream network and control points with the DEM stream network and snapped control points. Incorrectly snapped control points may be fixed using the

“Add Snapped Control Point” tool. Delete the incorrectly snapped control point and use this tool to replace it on the proper stream segment.

Take a look at the attribute table of the snapped control points. As each control point is snapped it is attributed with the arc ID that it is snapped to and it’s percent distance along that arc.

A.7.7 Creating Parameter Data Sets

Now that the control points are properly located along the basin stream network, you are almost ready to read the flow distribution parameters. Drainage area already exists in the form of the flow accumulation grid. The curve number and precipitation grids, however, require some processing. These grids contain an estimation of the parameter value, curve number or annual mean precipitation, over the area of each individual grid cell. To calculate the average curve number and precipitation over several sub-watersheds you sum up the products of each individual drainage area and parameter value and divide by the total area. This formula can be reproduced in GIS using a weighted flow accumulation function.

$$mean\ CN = \frac{flowaccumulation(flowdirection, CN) + CN}{flowaccumulation(flowdirection) + 1} \qquad (A.4)$$

The weighted flow accumulation sums the values of a grid over each flow accumulation grid zone. The weighted flow accumulation grid is then divided by the regular flow accumulation grid. These calculations are made on a cell-by-cell basis, so the parameter value of the current for cells with no flow accumulation. Each cell of the resulting grid then contains the average parameter value over the upstream drainage area.

The WRAP Parameters menu items, “Make Average Curve Number Grid” and “Make Average Precipitation Grid” apply this function to the original curve number and precipitation grids. Add the grid themes ***exrcngalb*** and ***exrpcpalb***. Create the average parameter grids for each. The resulting grids, ***avgcn*** and ***avgpcp***, should be copied into permanent grids : ***exracnalb*** and ***exrapcalb***.

A.7.8 Making the Control Point Network Diagram

Once the control points are snapped to an ordered stream network, you can determine the connectivity among control points using the WRAP Parameters menu item, “Make a Network Diagram.” For each control point, this script traces the stream network to the next downstream control point. The ID of this downstream control point is added to the attribute table of the snapped control points. At the same time a new line theme is built connecting each control point to it’s downstream point. This theme is output as ***network.shp***. The theme should be renamed ***exrnetalb.shp***.

A.7.9 Reading the Flow Distribution Parameters

At last! You’re ready to read the flow distribution parameters. First you’ll need to go to the WRAP Tools menu, click on “Set Parameter Grid Theme Names,” and do just that. Leave the flow length grid theme name as “none.” Some contractors have used an added parameter of channel length in simulating the flows at control points in the WRAP model. This parameter is not used in this exercise, but, if needed, the parameter grid theme name would be entered here.

The WRAP Parameters menu item “Report Control Point Parameters,” queries the flow accumulation, average curve number, and average precipitation grids at the location of each control point. The values are output in a new point shapefile, ***parameters.shp***. Rename this shapefile as ***exrparalb.***shp. If you have built the control point network with the snapped control point theme, then the IDs of the downstream control points are also carried over into the new attribute table. The flow accumulation value is automatically translated from number of grid cells into the drainage area with units of square miles. These are all the parameters you'll need to prepare an input watershed parameters file for the RECORDS preprocessor to WRAP.

A.7.10 Defining the Incremental Watershed Boundaries

The watershed boundaries are delineated from the DEM using the WRAP Parameters menu item "Delineate the Incremental Watersheds." Use the "Id" fields for the actual control point identifiers. This creates a polygon shapefile of the watershed boundaries, ***watrshed.shp***. Rename this shapefile as ***exrwsdalb.shp***. Open the theme attribute table and you'll notice that you actually have more polygons than control points. The watersheds are actually created from the flow direction grid as separate grid zones. Small "dangling polygons" are created when these grid zones are translated into polygons. They are deleted by running the WRAP Parameters menu item "Dissolve Dangling Polygons."

Each polygon has it's area automatically calculated in units of square miles. The average curve number and average precipitation values may be calculated over the incremental watersheds using the WRAP Tools menu item, "Average Grid by Polygons."

A.7.11 Quality Control

What large task would be complete without quality control? Quality control of the watershed parameters is important. These parameters determine how flows at each control point are simulated in the basin model, affecting real world decisions about water usage and availability. Drainage area is the most important parameter in the flow distribution calculations and the quality control process focuses on it. The precipitation and curve number parameters are accepted as being the best possible estimates given the geosaptial data sources currently available.

At it's most rigorous, quality control of the drainage area parameter would involve checking each watershed boundary against the topographic maps. For a real river basin, however, this would be a very difficult task. Large river basins are spread across hundreds of quadrangles and have hundreds of sub-watersheds. Small watershed boundaries are easily checked against the DRGs, but, as the drainage area increases, this becomes more difficult, as the boundary is spread over several quadrangles. A quality control procedure has been devised that directly checks both large and small drainage areas, and indirectly checks the intermediate areas.

The USGS gages typically have relatively large drainage areas. The flow accumulation drainage area value for each gage may be checked against it's USGS reported drainage area. Compare the drainage area you derived for control point 6010 (USGS gage 7342500) against the USGS reported value of 527 square miles. The values should agree within one or two percent. If the values disagree to a larger extent, make sure that you have located the point representing the gage correctly.

Experience with this project to date suggests that, using 1:24,000 scale DEMs, if the DEM stream network accurately reproduces the vector stream network and the control points are correctly located on the DEM stream network, then the resulting drainage areas are true to the 1:24,000 scale topography. The entire DEM stream network should be checked against the original vector stream network to ensure that there is no short-circuiting of the DEM stream network. Short-circuiting occurs in the DEM stream network when arcs in the vector stream network are located within one grid cell's distance of one another. When this happens, the flow direction grid may jump from one stream to the other if the DEM defines that route as the direction of steepest descent. If this occurs between large streams it can introduce large errors into the computed flow accumulation grid and the final flow distribution parameters.

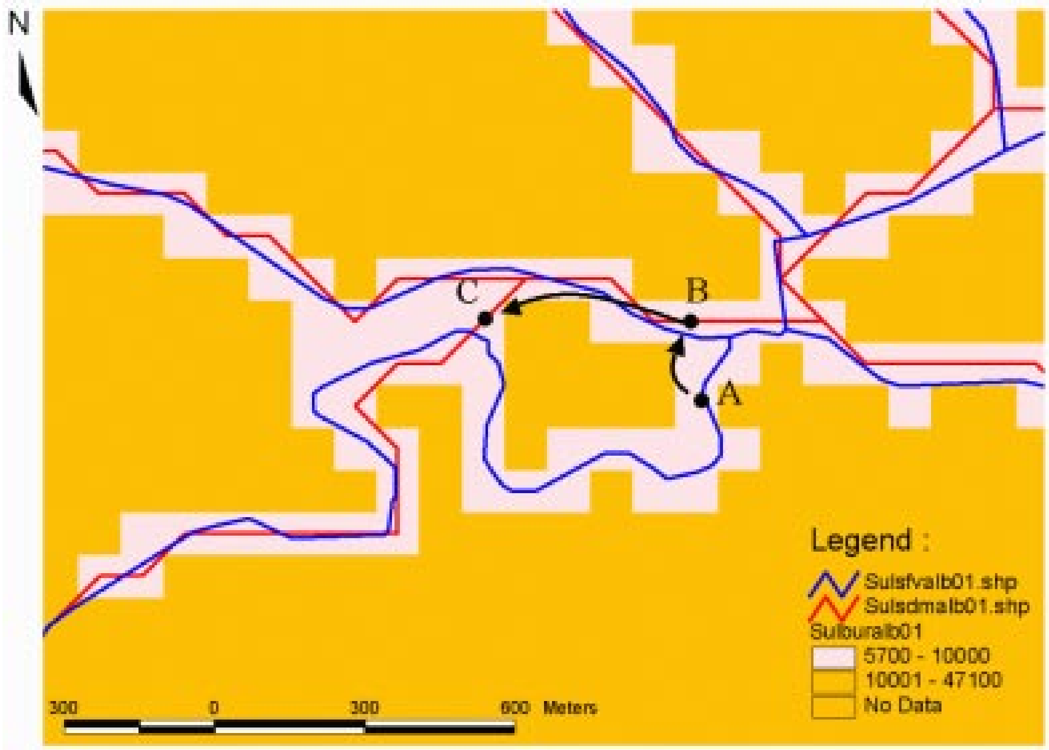


Figure A.9 : Example of Short-Circuiting Effect

Figure A.9 shows a stream junction in the Sulphur Basin. The DEM short-circuits the vector stream network causing the DEM stream junction to be located upstream of where the vector stream network locates it. Suppose a control point is to be placed at point "A." When the control point theme is snapped, this point will be snapped to the closest arc on the DEM stream network, at point "B." Note, however, that the flow accumulation at point B will include the upstream drainage from both the North and South forks. To best represent the drainage area for point A, point B can be deleted and replaced with point "C" using the "Add Snapped Control Point" tool. The drainage area defined for point C will slightly under-estimate the actual drainage area of point A. If this is a large discrepancy, the user must modify the original vector stream network by separating the two stream branches further apart than one grid cell so that the DEM will not short-circuit at this point and reprocess the DEM.

Check your ***exrsdmalb.shp*** against ***exrsfvalb.shp***. If there are any large-scale short-circuits in the DEM stream network you'll have to go back and edit ***exrsfvalb.shp*** so that the vector arcs are separated by more than one grid cell. If you've had to make modifications to the stream network, go all the way back to Section A.7.4, rebuild the burned DEM, and continue from there.

Finally, you can actually check small watershed boundaries against the DRGs. Small watersheds are most susceptible to errors in the drainage area definition. Experience at CRWR has shown that, as a rule of thumb, watersheds defined from a 1:250,000 scale DEM as smaller than 1,000 grid cells should be checked. Since we're using a 1:24,000 scale DEM, let's be safe and check anything less than 10,000 cells.

First, you'll need to project the watersheds into UTM so you can check them against the DRGs. Unfortunately, when you project the watersheds, before you can build the projected coverage polygons, you'll have to clean the coverage. The clean process wipes out any attributes in the resulting polygon attribute table. This means that you won't know which polygon belongs to which control point. So, in order to still be able to display the control point identifier with each watershed boundary, just build the projected coverage as a line coverage.

Arc : **shapearc *exrwsdalb exrwsdalb***
Arc : **project cover *exrwsdalb exrwsdutm* albtoutm.txt**
Arc : **build *exrwsdutm* line**
Arc : **copy *exrwsdutm temp***

Arc : **arcshape *temp* line *temp***
Arc : **kill *temp* all**
ArcView : **In View menu “File,” click on “Manage Data Sources”**
ArcView : **Rename *temp.shp* as *exrwsdutm.shp***

Now, check the smaller watersheds against the DRGs. The 1:24,000 DEMs define watersheds very accurately. There are three ways that the drainage area might be in error :

1. The control point is not correctly located,
2. A nearby tributary that defines part of the drainage area to the point has not been added to the stream network (and therefore not burned into the DEM),
3. Or, the DEM cannot accurately define the drainage area.

With the 1:24,000 scale elevation data, most errors in drainage area result from imprecise control point location. Make sure the control point is correctly located, and, if adjusted, re-run the watershed definition. If the watershed boundary captures a tributary that it should not, or fails to capture a tributary that it should, make sure that this tributary is present in ***exrsfvutm.shp***. If it’s not, go all the way back to section A.7.3, edit the stream network, and start over from there. If neither of these remedies results in an accurate drainage area, then the last resort is to delineate the watershed boundary yourself!

Drainage areas can be manually delineated using the DRG topography as a reference. Under the View menu, select "New Theme." Create a new polygon theme and use the Draw Polygon tool to delineate the correct watershed boundary. When you are done, convert this shapefile to a coverage, project it back into Albers, and build it as a polygon coverage. Now, each polygon will be attributed with it's area, albeit in square meters. You'll have to make the conversion to square miles yourself. Finally, you can calculate the incremental average curve number and precipitation values for the polygons as described in Section A.7.10.

A.8 RESULTS

When you're satisfied with your quality control, compare your results to the following. Your parameters will not exactly match these (the exact values depend on the exact control point locations), but they should be very close.

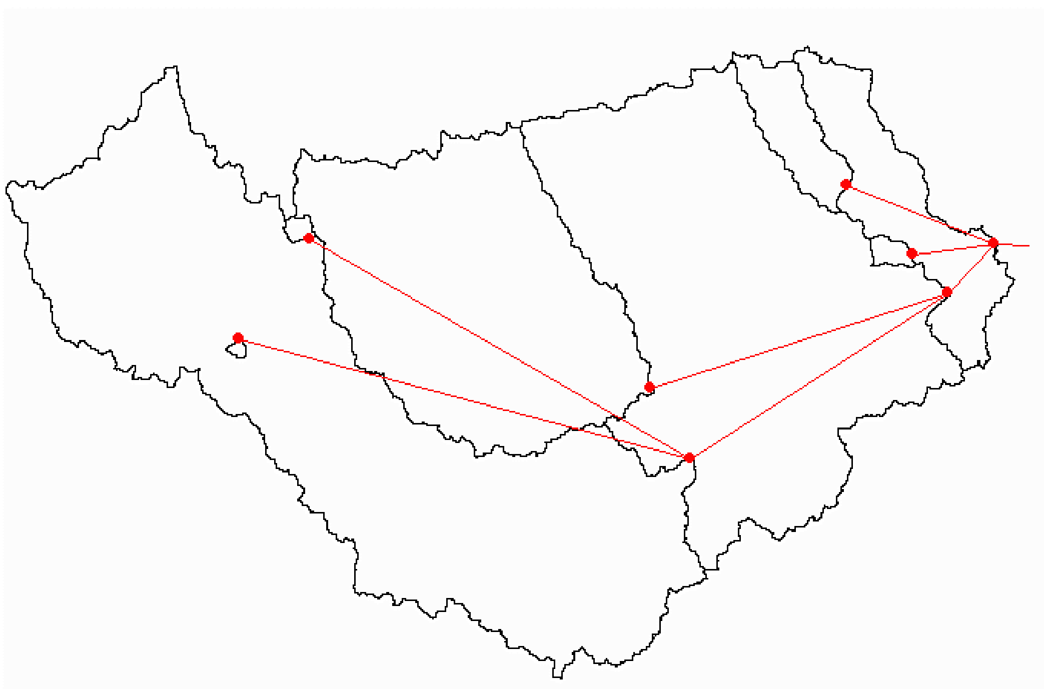


Figure A.10 : Control Point Network and Watersheds

			Total Upstream Areas				Incremental Areas		
CP	Type	D/S CP	Flow Accumulation (# cells)	Area (sq.mi.)	CN	Pcp (in./yr.)	Area (sq.mi.)	CN	Pcp (in./yr.)
6010	Stream gage	0	1683042	523.5740	69.34	42.67	31.0986	69.1281	43.4543
6020	Diversion point	6010	4856	1.5106	70.82	43.18	1.5110	70.8198	43.1797
6030	Diversion point	6010	38815	12.0749	69.76	43.00	12.0752	69.7639	43.0000
6040	Diversion point	6010	1539399	478.8884	69.33	42.61	163.4039	68.7301	43.3291
6050	Return flow	6040	351467	109.3371	69.83	42.41	109.3368	69.8341	42.4063
6060	Return flow	6040	662665	206.1471	69.55	42.15	204.9307	69.5360	42.1533
6070	Diversion point	6060	2832	0.8810	72.38	42.00	0.8807	72.3638	42.0000
6080	Diversion point	6060	1076	0.3347	69.77	42.00	0.3350	69.7712	42.0000

Table A.2 : Control Point Parameters

A.9 EXERCISE REFERENCES.

TNRCC, 1999. WAM : Water Availability Modeling, an Overview.
Internet Site : http://www.tnrcc.state.tx.us/admin/topdoc/gi/245/

Appendix B : Exercise 2

B.1 EXERCISE TABLE OF CONTENTS

B.2 INTRODUCTION

The Water Rights Analysis Package (WRAP) was developed at Texas A&M by Dr. Ralph Wurbs and David Dunn. It is currently being used to make water rights reliability assessments in all Texas river basins with the exception of the Rio Grande. Several versions of WRAP have been produced and it continues to evolve to meet the requirements of the Senate Bill 1 modeling project. For this exercise we'll use the November 1998 version.

The WRAP modeling package is a set of Fortran programs : RECORDS, WRAP-SIM, and TABLES. RECORDS is a preprocessor that can be used to develop naturalized streamflows at control points with unknown flow records, given the naturalized streamflows at known points, such as gages. WRAP-SIM is the actual simulation model. TABLES is a postprocessor used to organize the voluminous model output into user-specified formats.

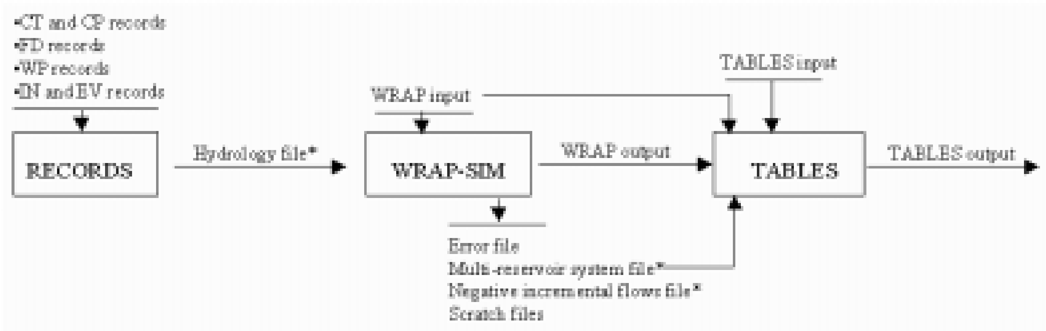


Figure B.1 : WRAP Modeling Package

Dr. Wurbs built the model, and he describes it thus :

> WRAP is a tool for assessing water availability for a river basin, or multiple-basin region, under a priority-based allocation system, such as the Texas water rights system. The simulation model is designed for evaluating capabilities for meeting existing and proposed water rights requirements and determining the unappropriated streamflows available for additional new permit applicants. WRAP-SIM performs sequential monthly water volume accounting computations associated with meeting water management /use requirements during a specified hydrologic period-of-analysis. Constant annual water use targets, which vary seasonally over the 12 months of the year, are combined with sequences of naturalized streamflows and reservoir evaporation rates representing basin hydrology. Water rights requirements include diversions, reservoir storage, instream flow needs, return flows, and hydroelectric power generation. The postprocessor program TABLES provides capabilities for organizing and summarizing WRAP-SIM simulation results by a variety of user-specified tables and reliability indices. The public-domain software package is generalized for application to any river basin, with input files being developed for the particular river/reservoir/use system of concern. (Wurbs, 1998)

A river basin system is represented in WRAP by the following components :

- **Control points** provide a way to specify locations in the model, based on upstream/downstream connectivity. Other components are associated with control points to reference their locations. Multiple components can be aggregated at a single control point.

- **Basin hydrology** is described by streamflows and net evaporation rates at each control point for each month of the period of analysis. Streamflows may be reported as either naturalized, unappropriated, or regulated flows. N**aturalized** streamflows are those calculated for each control point with the effects of man removed. Naturalized streamflows are input into the WRAP-SIM model. **Regulated** streamflows reflect the effects of reservoir and water rights demands. **Unappropriated** flows are the streamflows remaining after all required streamflow depletions are made. Regulated and unappropriated flows are output from the model.
- **Water rights** are basically described by diversion and/or storage amounts, types of use, and dates of priority. Specifically, each water right record consists of :
    1. a control point location
    2. annual diversion amount
    3. reservoir storage capacity
    4. priority number
    5. type of use
    6. return flow factor and return flow control point location

    The type of use (e.g. municipal, industrial, agricultural) is used to break down the annual diversion amount into monthly targets. To do this, the user defines monthly distribution factors for each type of water right. These water rights apply only to diversion of surface waters. Texas has no water rights system for pumping of groundwater. The priority date is the date the water right was first obtained. The appropriations doctrine upon which Texas water law is based says, "first in time is first in right," which means that the water right with the earliest priority date has the highest ranking among all water rights if a water shortage means that not all the rights can be satisfied from existing water supplies. Conversely, the water right with the most recent priority date has the lowest ranking and will be the first water right to be cut off if supply is limiting.

- **Reservoirs** provide storage capacity for water rights. A surface area/storage capacity relationship is used to calculate evaporation losses.
- **Return flows** represent water discharged back into the stream after use, from a water treatment plant for example.
- **Hydroelectric power** generation can be represented in the model as monthly energy targets and plant efficiencies. The model will try to satisfy the energy targets based on available streamflow and reservoir storage.

- **Reservoir system operating rules** define the operations of complex reservoirs with multiple water rights and priority dates.

RECORDS, WRAP-SIM, and TABLES all use text input files. These files must be formatted correctly or they'll cause incorrect output or hang up the programs. When you need to make changes to the input files in the exercises below, be sure to follow the field formatting. Within the fields, entries are right-justified, except for titles and comments. If one of the programs does hang up, remember that you can use Ctrl-C to interrupt execution in DOS.

B.3 GOALS OF THE EXERCISE

The intent of this exercise is to familiarize you with water availability modeling using the Water Rights Analysis Package (WRAP). By the end of the exercise, you will be able to :

- Use the RECORDS preprocessor to distribute naturalized streamflows from gaged locations to ungaged points
- Perform a basic water availability simulation using WRAP
- Use the TABLES postprocessor to format WRAP output
- Use WRAP as a tool to make assessments of water availability for future demands

B.4 EXERCISE DATA

The WRAP program elements and the files needed for this exercise can be downloaded at:

http://www.ce.utexas.edu/prof/maidment/grad/hudgens/research.html

The data is also included on the companion CD to this thesis, “CD1,” under the folder “exercise2.” You should have the following files for the exercise :

- **records.exe** = RECORDS pre-processor
- **sim.exe** = WRAP simulation program
- **tab.exe** = TABLES Post-processor
- **ctcp.txt** = input file for RECORDS
- **fd.txt** = input file for RECORDS
- **wp.txt** = input file for RECORDS
- **inev.txt** = input file for RECORDS
- **chapman1.dat** = WRAP-SIM data input file
- **chapman2.dat** = another WRAP-SIM data input file
- **example.ext**, **example1.txt**, **example2.txt**, **example3.txt** = examples of TABLES input files

B.5 EXERCISE STUDY AREA

In this exercise, we'll apply WRAP to a basin model. The Sulphur river basin is located in northeast Texas. Figure B.2 shows the Middle and South Sulphur Rivers above USGS gage 7342500 near Cooper, Texas.

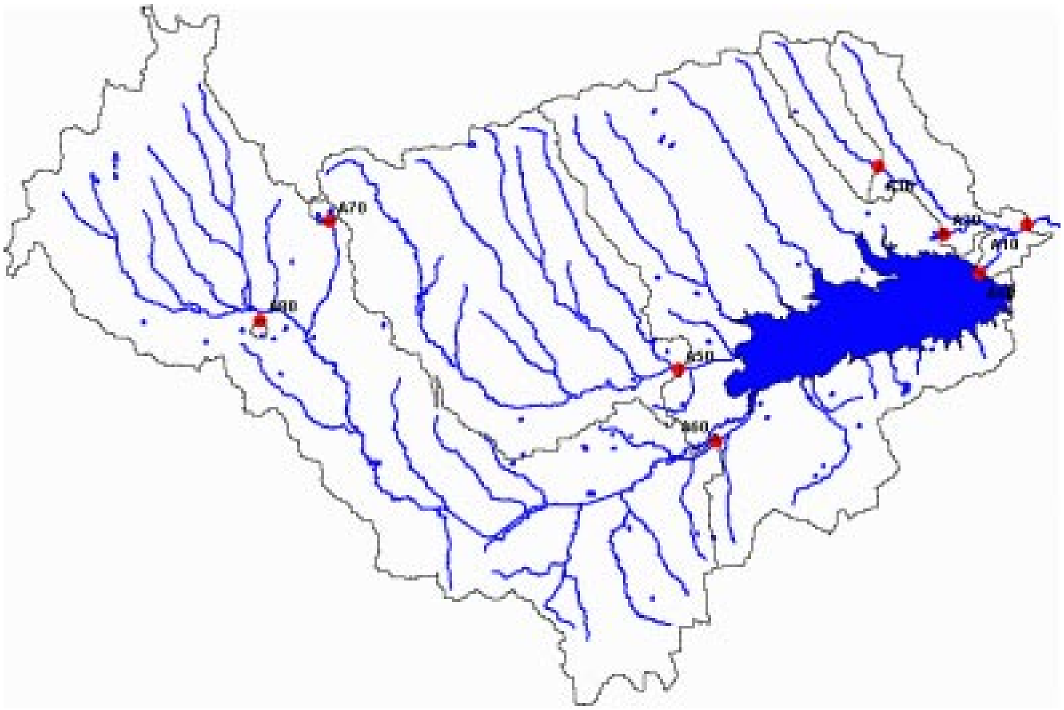


Figure B.2 : Exercise Study Area

The red points are the control points (8 of them) that we'll use to model this basin. The most downstream control point, A10, is the USGS gage. The model includes 13 water rights (that is, thirteen separate diversions, some of which belong to the same water right number) and 5 reservoirs in this watershed.
The large reservoir, modeled as control point A40, is Lake Chapman, which began impounding water in 1991. Water from this basin and from Lake Chapman is currently permitted primarily for water supply to cities in the area, and as far away as Irving, TX. Table B.1 gives a breakdown of the water rights in this watershed:

Water Right	Control Point	Permittee
4800	A20	City of Cooper
4395	A30	City of Cooper
4799	A40	City of Irving
4798	A40	North Texas MWD
4797	A40	Sulphur River MWD
4797	A40	City of Commerce
4795	A70	City of Wolfe City
4796	A80	Webb Hill Country Club

Table B.1 : Water Rights in the Study Area

Notice that not all control points are water rights. A10 is the USGS gage, and control points A50 and A60 are points where return flows from several nearby towns are put into the system. Return flows may represent outflows from water treatment and industrial processes or they may also be used to input increased flows in areas that use groundwater as water supply, then return it to the surface.

B.6 METHODOLOGY

B.6.1 Using RECORDS to Distribute Naturalized Streamflows

Naturalized streamflows are flows computed from historical data with the influences of human activity removed. Speaking mathematically :

Naturalized streamflow = Historical streamflow
+ Diversions
- Return flows
+ Reservoir depletions
+/- Changes in runoff due to changes in land use

Note that while other models may be helpful in preparing naturalized streamflows (e.g. reservoir simulation models), these calculations require a lot of old-fashioned research and work before even beginning to use a water availability model such as WRAP. In our basin, the naturalized flows for the years 1940-1996 have been determined by the contractors on the TNRCC Water Availability Modeling Program, R.J. Brandes and Associates, in the case of the Sulphur basin.

RECORDS develops WRAP hydrology records (streamflows and evaporation rates) at specified control points based on given records at other control points. Several options are available for methods of distributing naturalized streamflows from known to unknown points :

- **Flow distribution equation.** This equation can be used in several ways :
    - First, as a regression equation where the coefficients a,b, and c may be determined from a regression analysis of the results of a watershed precipitation-runoff model.

      $$Q_{ungaged} = a\left(Q_{gaged}\right)^{b} + c$$
    - Second, with b=1.0 and c=0, the equation may be used to distribute flows by defining the coefficient, a, as a ratio of the watershed parameters. Most often, a, is set equal to the drainage area ratio between the two points, but it could be defined as a more complex function of other watershed parameters.

      $$a = \frac{A_{ungaged}}{A_{gaged}}$$

      or

      $$a = \left(\frac{A_{ungaged}}{A_{gaged}}\right)^{N_1}\left(\frac{M_{ungaged}}{M_{gaged}}\right)^{N_2}\left(\frac{CN_{ungaged}}{CN_{gaged}}\right)^{N_3}\left(\frac{Other_{ungaged}}{Other_{gaged}}\right)^{N_4}$$

      where M = mean annual precipitation and CN is the average curve number for the upstream drainage area.

- The **modified NRCS CN method** is used in this exercise. This has the following steps :

  - Find the precipitation index, P, for the known (gaged) point, from the NRCS curve number equation

    $$Q_{known} = PA = \frac{(P - 0.2S)^2}{P + 0.8S} A \qquad where\ S = \frac{1000}{CN} - 10$$

  - Find the precipitation index, P, for the unknown (ungaged) point, by adjusting P for the known point by the ratio of mean precipitation between the two watersheds

    $$P_{ungaged} = P_{gaged} \left(\frac{M_{ungaged}}{M_{gaged}} \right)$$

  - Use the NRCS curve number equation above to find Q at the unknown point.

At CRWR, we use GIS to determine the drainage area, mean precipitation, and curve number for each control point in a basin model. This data becomes one of the input files for RECORDS so that the modified NRCS method can be used to distribute flows.

So, let's run RECORDS to prepare the hydrology input for our basin. First, let's get familiar with the input files. Four files are needed, they are :

1. Counter (CT) Records and Control Point (CP) Records, "CTCP.txt"

```
**CT IS THE COUNTER OF CONTROL POINTS, ETC.
CT 8 7 8 1 57 0
**A10 IS SOUTH SULPHUR RIVER NR COOPER, GAGE # 7342500
CP A70 A60 0 0 5
CP A10 OUT 0 0 0 A70
CP A20 A10 0 0 5 A70
CP A30 A10 0 0 5 A70
CP A40 A10 0 0 5 A70
CP A50 A40 0 0 5 A70
CP A60 A40 0 0 5 A70
CP A80 A60 0 0 5 A70
```

The CT record identifies how many records are present in each input file. Here it says, in order, 8 control points, 7 flow diversion records, 8 watershed parameter records, 1 control point with evaporation records, 57 years of hydrologic data, and the last "0" is a switch controlling the use of the multiplication factors in the CP records. The CP records define the connectivity and flow distribution methods among the control points. These records show: the control point, the next downstream control point (or OUT if it's an outlet), a multiplication factor for the inflow values (a "0" means to default to a value of 1), a multiplication factor for evaporation rates (a "0" means to default to a value of 1), a switch indicating the use of either total or incremental watershed areas (here the field is left blank meaning total watersheds are used), the "5" indicates that the NRCS flow distribution method is used ("0" means the values are input for the known point), and finally the location of the evaporation records ("A70" means they are copied from the known values given for CP A70).

2. Flow Distribution Specifications, "FD.txt"

Our version of this file is short and to the point. We are using the total upstream drainage areas and the modified NRCS method to distribute flows, so there's not much required here. For each record above we've simply input the unknown point, and the known point (A10) from which we'll be distributing flows.

```
FD   A70     A10                          0
FD   A20     A10                          0
FD   A30     A10                          0
FD   A40     A10                          0
FD   A50     A10                          0
FD   A60     A10                          0
FD   A80     A10                          0
```

3. Watershed Parameters, "WP.txt"

The watershed parameters are provided here:

```
**   CP    AREA     CN  PRECIP
WP   A70    1.03    72.8   42.0
WP   A10  541.01    69.6   42.8
WP   A20    1.66    71.5   44.0
WP   A30   12.44    69.9   43.0
```

WP A40 504.58 69.4 42.7
WP A50 106.34 69.9 42.4
WP A60 223.33 69.7 42.2
WP A80 0.29 70.0 42.0

The area is given in square miles, and the mean annual precipitation is in inches. The CN value ranges from 0 to 100. The precipitation and CN values are averages over the upstream drainage area from the given control point.

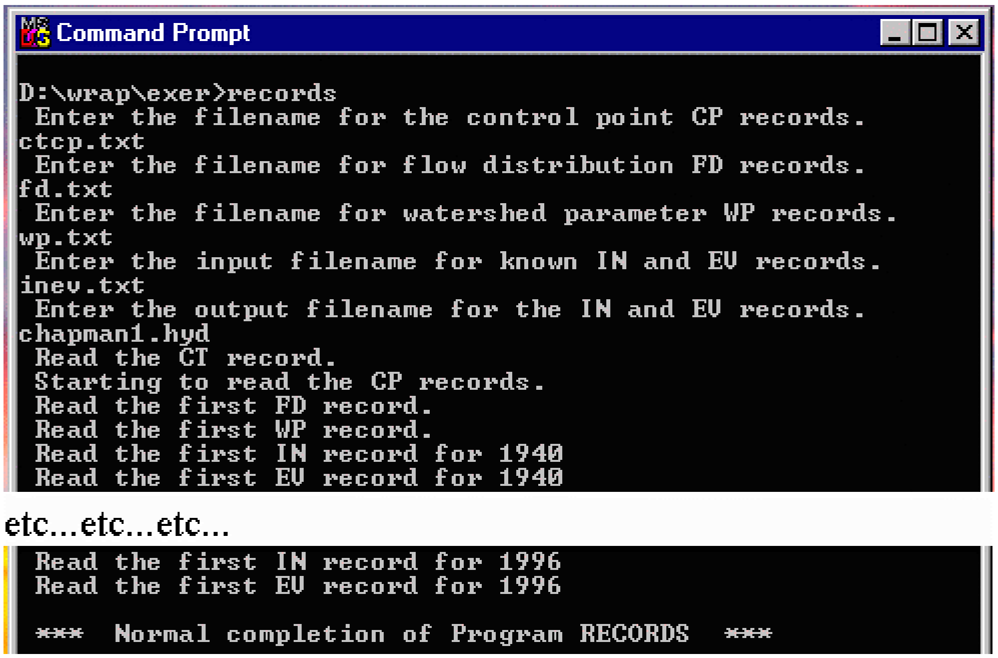
4. Inflow and Evaporation Records, "INEV.txt"

Here you have the naturalized streamflows (IN) and net evaporation rates (EV) for each known point, listed by month for each year of record. Streamflows are given in acre-ft./month. Net evaporation rates are defined here as the difference in gross reservoir evaporation minus precipitation, so a positive value indicates a positive net evaporation. These values are given in ft./month. This is an excerpt from our file :

```
** CP YEAR JAN FEB MAR APR MAY JUN
** JUL AUG SEP OCT NOV DEC
IN A10 1940 170 2809 2376 44621 26170 22500
IN 0 0 14608 276 586 47 31054 57673
EV A70 1940 0.03 -0.11 0.21 -0.27 -0.11 0.16
EV 0 0 0.23 0.55 0.52 0.28 -0.32 -0.31
IN A10 1941 16241 23605 63490 57131 83575 30013
IN 0 0 9076 2378 809 562 4512 10955
EV A70 1941 0.11 -0.10 0.01 -0.32 0.03 -0.35
EV 0 0 0.18 0.36 0.44 -0.21 0.14 -0.06
```

What this says is that the naturalized flow at gage A10 in year 1940 is 170 acre-ft/mo in January, 2809 acre-ft/mo in February, …, 57673 acre-ft/mo in December. The net evaporation at control point A70 is 0.03 ft/mo in January, -0.11 ft/mo in February, etc. The values for 1941 follow those for 1940, and so on until all data for naturalized flow at point A10 and net evaporation at point A70 have been specified.

Let's run RECORDS on this data. What you are doing now is determining the evaporation and the estimated naturalized flow at each control point in the basin. Double-click on the Records.exe file (or run it from an MS-DOS window) and answer the prompts. Be sure to call your output file, "Chapman1.hyd", this is necessary for the next step. Your run should look like this :



```
Command Prompt
D:\wrap\exer>records
 Enter the filename for the control point CP records.
ctcp.txt
 Enter the filename for flow distribution FD records.
fd.txt
 Enter the filename for watershed parameter WP records.
wp.txt
 Enter the input filename for known IN and EV records.
inev.txt
 Enter the output filename for the IN and EV records.
chapman1.hyd
 Read the CT record.
 Starting to read the CP records.
 Read the first FD record.
 Read the first WP record.
 Read the first IN record for 1940
 Read the first EV record for 1940
etc...etc...etc...
 Read the first IN record for 1996
 Read the first EV record for 1996

 ***  Normal completion of Program RECORDS  ***
```

Figure B.3 : RECORDS Run

RECORDS should run very quickly and output the file you specified. Your output file should look like this :

```
IN  A70  1940     1.     8.     7.    94.    57.    50.
IN          33.    1.     2.     1.    67.   120.
IN  A10  1940   170.  2809.  2376. 44621. 26170. 22500.
IN       14608.  276.   586.    47. 31054. 57673.
IN  A20  1940     2.    12.    11.   157.    95.    82.
IN          55.    2.     4.     1.   111.   200.
IN  A30  1940     5.    69.    58.  1049.   618.   533.
IN         347.    8.    15.     2.   733.  1353.
IN  A40  1940   138.  2517.  2123. 41056. 24004. 20617.
IN       13343.  230.   505.    33. 28515. 53135.
```

```
IN   A50    1940     35.    555.    470.   8728.   5126.   4409.
IN               2866.     56.    118.     10.   6080.  11275.
IN   A60    1940     62.   1109.    936.  18000.  10531.   9047.
IN               5859.    103.    224.     15.  12507.  23289.
IN   A80    1940      0.      1.      1.     23.     14.     12.
IN                  8.      0.      0.      0.     16.     30.
EV   A70    1940   0.030  -0.110   0.210  -0.270  -0.110   0.160
EV                 0.230   0.550   0.520   0.280  -0.320  -0.310
EV   A10   -1940    A70
EV   A20   -1940    A70
EV   A30   -1940    A70
EV   A40   -1940    A70
EV   A50   -1940    A70
EV   A60   -1940    A70
EV   A80   -1940    A70
```

This is the hydrology input file for WRAP-SIM. Now, all control points have streamflow and evaporation records for each hydrological year. Notice, that for evaporation rates, we have just copied values from the nearest known point. The evaporation rates are taken from values computed by the Texas Water Development Board (TWDB) that represent the average value over a 1^{o} X 1^{o} quadrangle.

You can import the text output of the hydrology file (Chapman1.hyd) into Excel by doing the following. Select the records you want to export in the hydrology file and copy them into a new text file. Be sure you save this new file as a .txt text file (not a Word document). Then, in Excel, go to File/Open, and set the "files of type:" window to Text Files. When you open the file, Excel will start its Text Import Wizard. In Step 1, choose "Fixed Width." In Step 2, you can modify the field widths if you like. Finally, choose the "General" column data format in Step 3, and you're done!

B.6.2 Using WRAP-SIM

The WRAP model is built around a monthly water availability balancing routine. The whole program is structured as follows:

- **Read input data**
    - read all input records except streamflows and evaporation rates
    - rank water rights in priority order "First in time is first in right"
    - other input data manipulations
- **Annual loop**
    - read streamflow and evaporation records for the year
    - **Monthly loop**
        - **Water right loop**
            - check streamflow availability
            - perform water balance computations
            - adjust available streamflows
            - write water right output records
        - write control point output records
        - write reservoir and hydropower output records

In the water right loop, each water right is given its diversion amount as long as streamflow or reservoir storage, not yet appropriated by senior rights, is available. Reservoir storage is calculated for each month as $S_2 = S_1 + D - R - E$. That is, the end-of-month storage equals the beginning-of-month storage + (D) the net streamflow depletion (inflows minus spills and releases to meet senior downstream water rights) - (R) releases or withdrawals to meet requirements of rights associated with this reservoir - (E) evaporation. Evaporation is computed as the evaporation rate times the average water surface area over the month. Since this depends on the storage values at the beginning and end of the month, an iterative solution is required.

Water right seniority is fundamental to the simulation. The most senior right in the basin meets its diversion target and refills its reservoir storage capacity as if no other water rights existed.

To run the WRAP-SIM program, you need an input file and the basin hydrology records. We just created the hydrology file for this basin, and luckily for us, an input file has already been prepared for this model. The input file describes all of the model components and sets the simulation specifications. Take a look at the file "Chapman1.dat" As with RECORDS, a two-character identifier is used for each type of record. Types of records in this input file include :

Record Code	**Description**
T1, T2, T3	titles or headings
**	comments
JG	water rights groups for output
JD	job control
UC	monthly use factors
CP	control point information
CI	constant monthly inflow or outflow
WR	water right
WS	water right reservoir storage
IF	instream flow requirement
SV	storage/area table volumes
SA	storage/area table areas
ED	end of data for the basin description

Table B.2 : WRAP-SIM Input File Record Codes

Since we're concerned with water rights analysis, let's focus on the water rights records. We have thirteen water rights in this model, and the records look like this :

```
WR  4800     A20     273    480019770103
WR  4395     A30    1518    480019830906
WR 4799M     A40   44820   4799M19651119                   WRCHAP
WR 4799I     A40    9180   CONST19651119                   WRCHAP
WR  4798     A40   54000    479819651119                   WRCHAP
WR 4797AM    A40   26960   4797M19651119                   WRCHAP
WR 4797AI    A40   11560   CONST19651119     2   0.425     WRCHAP
WR 4797BM    A40       0   4797M19651119                   WRCHAP
WR 4797BI    A40       0   CONST19651119                   WRCHAP
WR 4795_1    A70      69    479519251231
WR 4795_2    A70     232    479519570812
WR 4796_1    A80      80    479619680311
WR 4796_2    A80       0    479619830418
```

Each record tells you, in order, the water right number, the control point, the annual permitted diversion (acre-ft/year), the use type (each use has associated monthly distribution factors for the annual diversion), the priority date (given as YYYYMMDD), the type of water right (a WRAP definition for how the water right is treated in the model, where a blank indicates type 1), and there may be a return flow factor and a group identifier.

Now lets run the model. WRAP-SIM works with a common filename, and identifies the different input and output files by their extension. In this case, we've called the hydrology and data input files "Chapman1.hyd" and "Chapman1.dat", so the output files will all be named "Chapman1" as well. Double-click on the Sim.exe file, or run the file from a DOS prompt. Be sure and specify the full path and filename for the root file "Chapman1", for example

"Y:/hudgens/wrap/exercise/chapman1". The scratch files are used internally by WRAP and I suggest you just send them to your local temp directory. Your run should look like this:

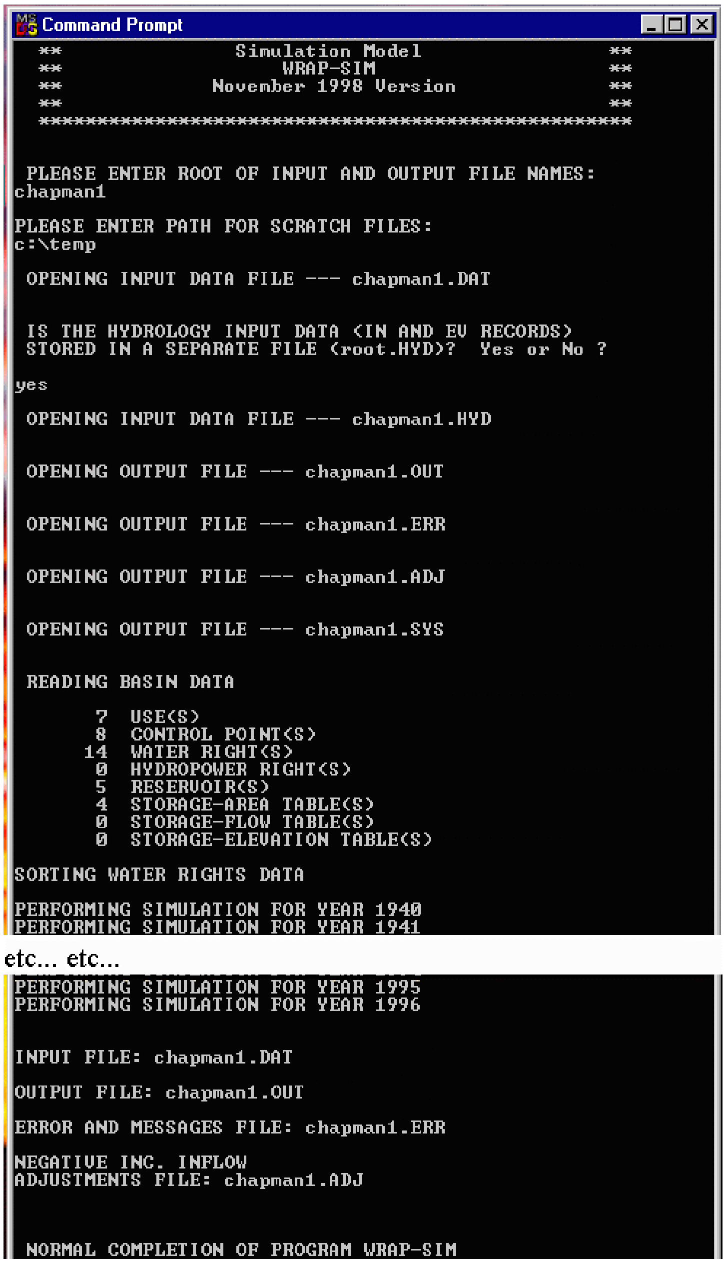


Figure B.4 : WRAP-SIM Run

WRAP writes a lot of text output, and it's not particularly interesting by itself. Here's what the raw output for water rights looks like in the first few results from our simulation :

```
Program SIM    (November 1998 Version)  Output File
    WRAP - SIM  -- RUN 1
    CHAPMAN WATERSHED
    MARCH 1999
  1940    57    12     8    14     5
4795_1      0.0      6.8      2.1    417.0      1.0       1.0      0.0  1940   1
4795_2      0.0     22.9      3.2    823.0      0.0       0.0      0.0  1940   1
4799M      0.0   2917.8    585.6 306943.3    446.6     446.6      0.0  1940   1
4799I      0.0    779.5    585.1 306164.2      0.0       0.0      0.0  1940   1
4798      0.0   3930.8    582.8 302235.7       0.0       0.0      0.0  1940   1
4797AM    0.0  2286.2    581.5 299950.8       0.0       0.0      0.0  1940   1
4797AI      0.0    981.6    580.9 298969.7       0.0       0.0      0.0  1940   1
4797BM    0.0      0.0    580.9 298969.7       0.0       0.0      0.0  1940   1
4797BI      0.0      0.0    580.9 298969.7       0.0       0.0      0.0  1940   1
4796_1      0.0      3.5      0.4     35.2       0.0       0.0      0.0  1940   1
IF4799      0.0    307.6      0.0      0.0       0.0       0.0    307.6  1940   1
307.6      0.0  IF
4800      0.0     21.4      2.0    142.6      2.0       2.0      0.0  1940   1
4796_2      0.0      0.0      0.5     56.0      0.0       0.0      0.0  1940   1
4395      0.0    119.2     19.3   4756.6      5.0       5.0      0.0  1940   1
```

These records are output for each water right and control point by month.

These water right output records show you :

- the water right identifier
- diversion shortage
- permited target diversion (the water right amount)
- evaporation
- end-of-period storage
- streamflow depletion
- available streamflow
- releases from other reservoirs
- year
- month

B.6.3 Formatting Output in TABLES

TABLES is a postprocessor for organizing the WRAP output file into more user-friendly summaries. It requires a WRAP output file, in some cases the WRAP input file, and a TABLES input file specifying the summaries to be output. There are four job types executed by TABLES. Within each job type, there are several records. Each record specifies a different type of summary or output to be made.

- Job type 1 records specify tabulations of input data from the WRAP input file.
- Job type 2 records develop summaries from the water right, control point, and reservoir data in the WRAP output file.
- Job type 3 records translate WRAP streamflow data into HEC-3 or HEC-5 formats.
- Job type 4 records summarize reservoir release and hydropower output data.

Our interest is mainly in the job type 2 records. Here are the records of interest to us :

- **2SCP Record.** Summarize control point data.
- **2SWR Record.** Summarize water rights data, same format as 2SCP.
- **2SRE Record.** Summarize reservoir data, same format as 2SCP.
- **2REL Record.** Summarize reliability and shortages.
- **2NAT Record.** Naturalized streamflow table.
- **2UNA Record.** Unappropriated streamflow table, same format as **2NAT**.
- **2DEP Record.** Streamflow depletion table, same format as 2NAT.
- **2SHT Record.** Shortage table, same format as 2NAT.
- **2STO Record.** Storage table, same format as 2NAT.

The "example.ext" file is an example TABLES input file that includes all of these records. It looks like this:

```
TITL SIMULATION OUTPUT
COMM PRINT TITLE PAGE
PAGE
COMM CONTROL POINT SUMMARY FOR ALL CONTROL POINTS
2SCP   1   0
COMM CONTROL POINT SUMMARY FOR SELECTED CONTROL
POINTS
2SCP   1   1     A40
COMM WATER RIGHTS SUMMARY
2SWR   1   0
COMM SAME FORMAT AS ABOVE FOR SELECTED WATER
RIGHTS
COMM SUMMARY OF ALL RESERVOIRS
2SRE   1   0
COMM SELECTED RESERVOIRS ONLY
2SRE   1   1  CHAPMN
COMM RELIABILITY SUMMARY OF ALL WATER RIGHTS
2REL   1   0
COMM SAME FORMAT AS ABOVE FOR SELECTED
COMM NATURALIZED STREAMFLOWS AT CONTROL POINTS
2NAT   0   0
COMM SAME FORMAT FOR UNAPPROPRIATED STREAMFLOWS
2UNA   0   0
COMM SAME FOR STREAMFLOW DEPLETION
2DEP   0   0
COMM SAME FOR SHORTAGE TABLE
2SHT   0   0
COMM SAME FOR STORAGE TABLE
2STO   0   0
ENDF
```

There are some additional records that add titles and comments, and mark the end-of-file:

Record Code	Description
TITL	titles or headings
COMM	add comments
PAGE	add header page to the output file
ENDF	end of input data file

Table B.3 : Additional TABLES Records Descriptions

Note that you must have the ENDF record at the end of the file. These records are formatted in two ways :

- The 2SCP, 2SWR, and 2SRE records all have first either a "0" or "1" for an annual or monthly summary respectively, and second either a "0" or positive integer for listings of all elements or selected elements respectively. If only selected elements are requested, they are then listed. Note that for reservoirs the reservoir name is entered (not the control point).

- The 2REL record is similar to the above but has first either a "0" or "1" to indicate either control points or water rights, then second a "0" or positive integer for all or selected elements. The 2NAT, 2UNA, 2DEP, 2SHT, and 2STO records are formatted the same as the 2REL.

A TABLES input file must have a ".ext" extension on the filename, but it does not have to have the same filename as the WRAP-SIM file you used. The example tables input file for this exercise, "Example.ext", includes all of the type two jobs listed above. To minimize the output, only run one or two jobs at a time, instead of putting all of them in one file as in the example. By now, you can probably guess how to run TABLES. Just double-click on the Tab.exe file or run it from a DOS prompt. The Tables input file that presents just the output at point

A10 is called **example1.txt**. The Tables output file is called **output1** (this could have been any name). The Wrap output file name is **chapman1.out**, which you computed in the previous step. The DOS dialog is as follows:

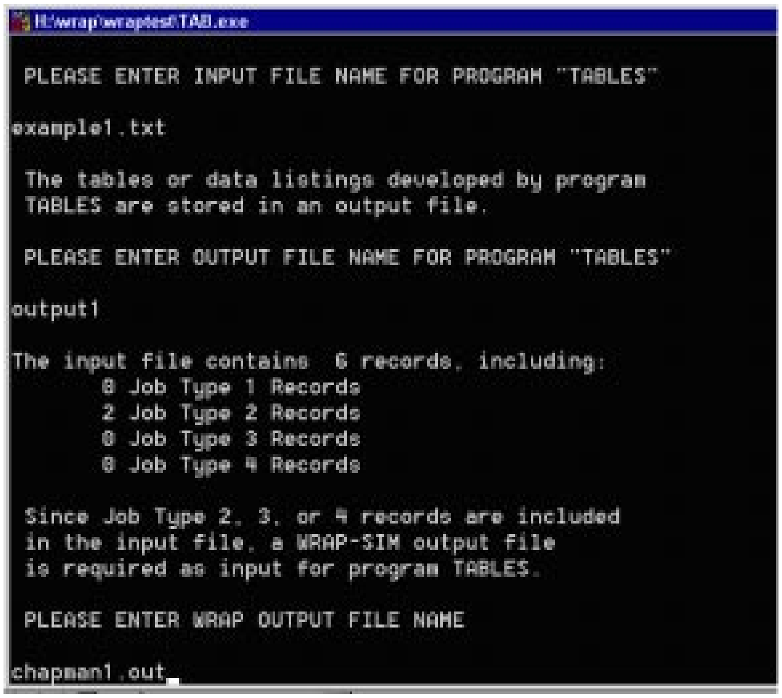


Figure B.5 : TABLES Run

B.7 WATER AVAILABILITY PLANNING

The water availability models being constructed under Senate Bill 1 are being used by TNRCC to approve new applications for surface water rights. In this section you'll look at the effects of increased demand on Chapman reservoir.

Irving, Texas is located between Dallas and Fort Worth. It presently has a population of about 160,000 but there are 3.2 million people in the Dallas/Ft. Worth metropolitan area and the population is expected to grow rapidly. As we've seen above, Irving currently holds rights to 54,000 acre-ft/year of water out of Chapman reservoir. If the population doubles, an increase of 160,000 persons, could their water demand be met from Chapman reservoir? Assuming a use rate of 200 gallons per capita per day, that is equivalent to an increased demand of 32MGD or about 36,000 acre-ft/yr. The file "Chapman2.dat" has this diversion amount entered as a new water right, water right #5000. The new water right will be the most junior in the basin, with a priority date of March, 1999. Make a copy of the "Chapman1.hyd" hydrology file and name it as "Chapman2.hyd" and run WRAP-SIM. The DOS dialog looks like this:

Figure B.6 : WRAP-SIM Run for Irving Scenario

First, lets take a look at the time series of storage levels in Chapman Reservoir. Another Tables input file has been prepared for this called example2.txt. The dialog to run this file is as follows:

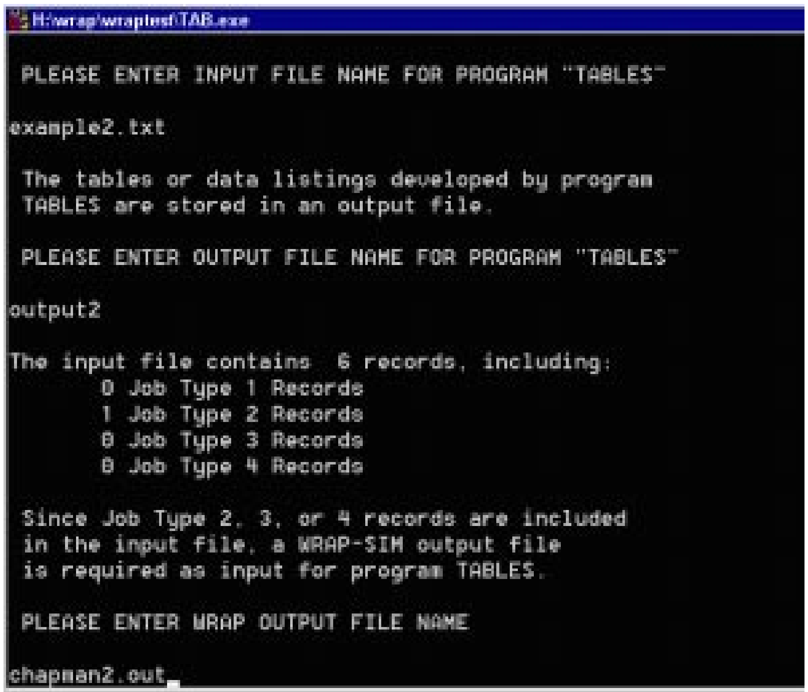


Figure B.7 : TABLES Run for Irving Scenario

Use Notepad to open this file. You'll see a monthly summary of end of period storage in column 3 (EOP Storage).

Now, lets examine the impact of adding the new water right to the performance of the other water rights dependant on Chapman Lake. Another Tables input file has been prepared called **example3.txt** which gives the reliability information for water right locations. Run this file to example the results from both **chapman1.out** and **chapman2.out** and compare the resulting reliabilities. The DOS dialog is the same as that shown above, except that you substitute example3.txt for example2.txt, and give new output file names to correspond to your new results, e.g. output3 and output3 corresponding to inputs from chapman1.out and chapman2.out respectively.

B.8 EXERCISE REFERENCES

"Documentation of New Features in the November 1998 Version of the Water Rights Analysis Package (WRAP)." Wurbs, R.A., November, 1998.

"Water Rights Analysis Package (WRAP) Model Description and Users Manual." Dunn, D.D., Wurbs, R.A., October, 1996.

Appendix C : Data Dictionary

C.1 DATA COMPACT DISC ONE

This CD contains the Texas state and Sulphur basin databases described in this thesis. This section contains the data dictionary for these two databases. The CD also contains the coverages and files used in Exercises 1 and 2 (Appendices A and B) and text files of the code presented in Appendix D.

Theme	**Description**	**Class**	**Attributes**	**Description**
Onedegalb	One degree latitude by one degree longitude mesh	Polygon	Usgs_id	USGS identifier of one degree box
Quadsalb	7.5 minute quadrangle mesh	Polygon	Standard	
Sulacnalb01	Area averaged curve number grid	Float	Value	Average curve number value over upstream flow accumulation area
Sulapcalb01	Area averaged mean annual precipitation grid	Float	Value	Average precipitation value over upstream flow accumulation area. Units of in./yr.
Sulbasalb01	River basin boundary	Polygon	Basin_num	Texas river basin number
			Basin_name	Basin name
			Short_name	Abbreviated basin name
			Tmdlreg	Texas TMDL region identifier
Sulbf2utm01	River basin boundary, buffered by 11,000 m	Polygon	Standard	
Sulbufalb01	River basin boundary, buffered by 10,000 m	Polygon	Standard	
Sulburalb01	Dem burned with mapped stream network	Integer	Value	Elevation values are original DEM values along mapped streams, and DEM plus a constant outside of the stream network. Units of cm.
Sulcngalb01	Curve number grid of river basin	Integer	Value	Curve number
Sulctlutm01	USGS centerlines through open water features	Line	Standard	

Theme	Description	Class	Attributes	Description
Sulfacalb01	Flow accumulation grid	Float	Value	Flow accumulation of upstream cells
Sulfcpalb01	Final control point coverage. Includes all (and only those) control points for which parameters are to be determined	Point	Id Type	Control point identifier Type of control point -Stream gage -Other primary -Diversion point -Return flow -Other secondary
Sulfdralb01	Flow direction grid	Integer	Value	Flow direction values 1,2,4,8,16,32,64,128
Sulfilalb01	Burned DEM with internal sinks filled	Integer	Value	Elevation. Units of cm.
Sulnetalb01	Model network lines connecting each control point to the next downstream control point (or basin outlet)	Line	Standard	
Sulparalb01	Snapped control points attributed with flow distribution parameters	Point	Id Type Dscp Demfac Area_sq_mi	Control point identifier Type of control point -Stream gage -Other primary -Diversion point -Return flow -Other secondary Identifier of next downstream control point "0" = basin outlet Flow accumulation value. Units of # cells. Total upstream drainage area, calculated from flow accumulation. Units of sq. mi.

Theme	Description	Class	Attributes	Description
			Avgcn	Average curve number over total upstream drainage area
			Avgpcp	Average precipitation value over total upstream drainage area. Units of in./yr.
			Flowlength	Optional field (not used)
Sulpcpalb01	Annual mean precipitation grid	Integer	Value	Annual mean precipitation. Units of in./yr.
Sulqcwalb01	Manually delineated quality control watersheds	Polygon	Incavgcn	Average curve number over incremental watershed area
			Incavgpcp	Average precipitation value over incremental watershed area
			Cp	Control point identifier
				Note : standard attribute Area in units of sq. meters
Sulrfealb01	RF3 coverage of HUC8 watersheds surrounding the river basin. RF3 attributes are removed.	Line	Standard	
Sulrfialb01	RF3 coverage of river basin	Line	RF3 attributes	RF3 attributes are available from EPA (1994) at http://www.epa.gov/OWOW/NPS/rf/techref.html
Sulsbnalb01	Stream theme used to burn DEM. Sulsfvalb01 merged with Sulsfxalb01.	Line	Standard	
Sulscpalb01	Snapped control points	Point	Id	Control point identifier

Theme	Description	Class	Attributes	Description
			Type	Type of control point -Stream gage -Other primary -Diversion point -Return flow -Other secondary
			Arcid	Arc identifier of arc in stream theme to which the point was snapped
			Distance	Percentage distance of point along the arc identified by Arcid, from from-node to to-node
			Dscp	Next downstream control point
Sulsdmalb01	Stream network defined by tracing flow direction paths from headwaters of vector stream network	Line	Arcid	Unique arc identifier assigned by connectivity script
			Dsarcid	Identifier of next downstream arc
Sulsfvalb01	Basin stream network with all edits completed	Line	Standard	
Sulsfxalb01	Stream network external to basin, with all edits completed	Line	Standard	
Sulsglalb01	Stream gage locations in river basin	Point	Usgsgage_id	USGS identifier of gage
			X_coord	Longitude of station
			Y_coord	Latitude of station
Sulswvalb01	Working version of basin stream network	Line	Standard	
Sulswxalb01	Working version of stream network external to basin	Line	Standard	

Theme	Description	Class	Attributes	Description
Sulwqbalb01	TNRCC water quality segment boundaries within the river basin	Line	Temp_id	TNRCC assigned identifier
			Basin_num	Texas river basin number
Sulwqsalb01	TNRCC water quality segments within the river basin	Polygon	Name	Name of water feature
			Seg_id	TNRCC segment identifier
			Basin_num	Texas river basin number
Sulwrdalb01	Water right record locations extracted from TNRCC water rights database	Point	Wrights_id	Unique record identifier corresponding to "Uniques" field in TNRCC water rights database Note : the Wrights_id field may be used to link the attribute table to the TNRCC water rights database
			X_coord	Longitude of point
			Y_coord	Latitude of point
Sulwrualb01	Water right update points provided by TNRCC	Point	Id	Water right record unique identifier from TNRCC water rights database
			Remarks	Remarks by TNRCC staff
Sulwsdalb01	Incremental watersheds for control points	Polygon	Cp	Control point identifier
			Incarea_sq	Area of incremental watershed. Units of sq. mi.
			Incavgcn	Average curve number over incremental watershed area
			Incavgpcp	Average precipitation value over incremental watershed area

Theme	Description	Class	Attributes	Description
Texbasalb	Texas river basins	Polygon	Basin_num	Texas river basin number
			Basin_name	Basin name
			Short_name	Abbreviated basin name
			Tmdlreg	Texas TMDL region identifier
Texcngalb	Curve number grid clipped to state boundary	Integer	Value	Curve number
Texctlutm	USGS centerlines for open water features within state	Line	Standard	
Texctyalb	County coverage for EPA region 6	Polygon	Fips	US county identifier
			St	State
			Cntyname	County name
			Stcofips	St county identifier
Texhucalb	Coverage of 8 digit HUC watershed boundaries	Polygon	Huc	HUC8 code
Texmesutm_ 15	Quadrangle mesh attributed with USGS quadrangle identifiers	Polygon	Label	Alphanumeric identifer used in creating coverage
			X_coord	Longitude of lower right corner
			Y_coord	Latitude of lower right corner
			Code	Unique USGS quadrangle identifier
			Cd_name	Optional field (not used)
Texpcpalb	Annual mean precipitation grid clipped to state boundary	Float	Value	Annual mean precipitation. Units of in./yr.

Theme	Description	Class	Attributes	Description
Texwqbalb	TNRCC water quality segment boundaries within the state	Line	Temp_id	TNRCC assigned identifier
			Basin_num	Texas river basin number
Texwqsalb	TNRCC water quality segments	Polygon	Name	Name of water feature
			Seg_id	TNRCC segment identifier
			Basin_num	Texas river basin number
Texwrdalb	Water right record locations extracted from TNRCC water rights database	Point	Wrights_id	Unique record identifier corresponding to “Uniques” field in TNRCC water rights database

C.2 DATA COMPACT DISC TWO

This CD contains the Location Review Database for the Sulphur basin described in Section 3.2. This section contains the data dictionary for this database.

Theme	Description	Class	Attributes	Description
Sulbasutm01	River basin boundary	Polygon	Basin_num	Texas river basin number
			Basin_name	Basin name
			Short_name	Abbreviated basin name
			Tmdlreg	Texas TMDL region identifier
Sulrfiutm01	RF3 coverage of river basin	Line	RF3 attributes	RF3 attributes are available from EPA (1994) at http://www.epa.gov/OWOW/NPS/rf/techref.html
Sulsglutm01	Stream gage locations in river basin	Point	Usgsgage_id	USGS identifier of gage
			X_coord	Longitude of station
			Y_coord	Latitude of station
Sulwrdutm01	Water right record locations extracted from TNRCC water rights database	Point	Wrights_id	Unique record identifier corresponding to “Uniques” field in TNRCC water rights database Note : the Wrights_id field may be used to link the attribute table to the TNRCC water rights database
			X_coord	Longitude of point
			Y_coord	Latitude of point
Texmesutm_15	Quadrangle mesh attributed with USGS quadrangle identifiers	Polygon	Label	Alphanumeric identifer used in creating coverage
			X_coord	Longitude of lower right corner
			Y_coord	Latitude of lower right corner

Theme	Description	Class	Attributes	Description
			Code Cd_name	Unique USGS quadrangle identifier Optional field (not used)
Uniques.dbf	TNRCC water rights database, indexed by unique identification number field "Unique"	DBF file	Various	Data dictionary for this file is available from TNRCC.
Wrap1117.apr	WRAP Parameters ArcView 3.1 project file	APR file	None	
O33094b1	TIFF image files of scanned USGS topographic map	TIF file	None	
O33094b1.tfw	TFW file associated with corresponding TIFF file	TFW file	None	

Appendix D : Code

Code	File Name	Page
Reprodrg.txt		269
Albtodem.txt		269
Albtoutm.txt		270
Bastoutm.txt		270
Demtoalb.txt		271
Gagtoalb.txt		271
Gagtoutm.txt		271
Utmtoalb.txt		272
Z14toz15.txt		272

Table D.1 : Index to Program Codes in Appendix D

```
'Name: hydro.DemPstDslvMg, hydro01.ave
'Headline: Called by DemPstDslv
'Self: {TheView,PFtab,PShape,DsvList,DsvRecList,DDList}
'Returns:
'Description: Merge polygons with certain characteristics.
'Topics:
'Search Keys:
'Requires:
'History: 4/2/97 Modified 11/23/97 by SMR
'--- Made changes so that dangling polygons
'--- are automatically dissolved into adjacent
'--- polygons without prompting the user each time.
'
'This script is called for each set of polygons being
'considered for dissolve.

TheView=SELF.Get(0)
PFtab=SELF.Get(1)      'Polygon Ftab
PShape=SELF.Get(2)     'ShapeField
DsvList=SELF.Get(3)    'Shape
DsvRecList=SELF.Get(4) 'Recs to be dissolved
DDList=SELF.Get(5)     'Recs to be eliminated
DsvCnt=DsvList.Count
OrgShpV=DsvList.Get(0)
OrgRec=DsvRecList.Get(0).Clone
tmpshp=orgshpv
'--- loop through a list of polygons with the same
for each i in 1..(DsvCnt-1)
  DsvShpV=DsvList.Get(i)

  DsvRec=DsvRecList.Get(i).Clone
'--- New as of 12/15/97 : Always merge polygons that are on a
diagonal
'--- into one polygon.

   'gcode=pftab.returnvalue(pftab.findfield("gridcode"),dsvrec)
   'gcode2=pftab.returnvalue(pftab.findfield("gridcode"),orgrec)

   pshpv=tmpshp.returnmerged(dsvshpv)
   tmpshp=pshpv

   DDList.Add(DsvRec)

end
'--- set the shape
pshapef=pftab.findfield("shape")
pftab.setvalue(pshapef,orgrec,pshpv)
'' 2.  z:\seann\txdot\hydro.dempstdslvmg of 76 lines,
''z:\projects\txdot\scripts\hydro.dempstdslvmg_diag of 49 lines,
''z:\projects\txdot\scripts\hydro.dempstdslvmg_diag of 50 lines,


''z:\projects\txdot\scripts\hydro.dempstdslvmg_diag of 51 lines,
```

```
'Name: hydro.RmvRecsLst, hydro02.ave
'Headline: hydro.rmvRecsLst,{Ftab,TheList,False}
'Self: {aVtab,RecList,RemainEditabl}
'Returns: nil
'Description: Remove Records specified in a list.
'Topics:
'Search Keys:
'Requires:
```

```
' History: 4/3/97

TheFtab=SELF.Get(0)
TheList=SELF.Get(1)
RemainEditable=SELF.Get(2)
if(TheFtab.CanEdit)then
  TheFtab.SetEditable(True)
else
  Msgbox.info("Can't
Edit"++TheFtab.getName,Script.The.GetName)
  return nil
end
TheBitMap=TheFtab.GetSelection
TheBitMap.ClearAll
TheFtab.UpdateSelection
TheBitMap=TheFtab.GetSelection
For each i in TheList
  TheBitMap.Set(i.Clone)
end
TheFtab.RemoveRecords(TheBitMap)
TheFtab.SetEditable(RemainEditable)
```

' Script: wrap.addcp_tool, wrap01.ave

```
'
' Description: Adds a  control point to
'   an existing coverage or creates a new point
'   coverage with control point locations, the user is
'   asked to input the id number and type of the
'   point added.
'
' History: Modified 9/7/99 by Brad Hudgens from original by
Richard Gu, CRWR, 1998

theDir=av.getproject.getworkdir

pntThmName=_cpThm
if (_cpThm=nil) then
  msgbox.info("Set control point filenames in WRAP Tools
menu","WRAP Parameters")
  exit
end
pntFileName=FN.merge(Thedir.AsString,_cpThm+".shp")

'Identify the tool that called the script
theTool=av.getactivegui.gettoolbar.getactive.gettag

'Get the control point
theView=av.getactivedoc
pt=theView.getdisplay.returnuserpoint

'Input type and id number of control point
options={ "Diversion point","Return flow","Other
secondary","Stream gage","Other primary"}
choise=msgbox.choiceasstring(options,"Choose the type of
control point:","WRAP Parameters")
if (choise=nil)then
  msgbox.info("No Selection","")
  exit
end
id_string=msgbox.input("Enter the ID number:","WRAP
Parameters","0")
if (id_string.isnumber) then
  id_number=id_string.asnumber
```

```
else
  msgbox.info("ID must be an integer","Error")
  exit
end

’If this is the first point, make the FTab
pntThmName=_cpThm+".shp"
if(theView.findtheme(pntThmName)=nil) then

  pntFtab=ftab.makenew(pntFileName,point)
  pntTheme=ftheme.make(pntFtab)

  pntFields=list.make
  pntFields.add(field.make("ID",#Field_Long,12,1))
  pntFields.add(field.make("Type",#Field_VChar,20,0))
  pntFieldsC=pntFields.deepclone

  pntFtab.addFields(pntFieldsC)
  theView.addTheme(pntTheme)

  if(pntFtab.canedit) then
    pntFtab.seteditable(true)
  else
    msgbox.error("Can’t edit the output theme.","WRAP
Parameters")
    exit
  end
  pntTheme.setvisible(true)

’If this is not the first point, get the FTab
else

’Check Ftab for duplicate id numbers
  pntTheme=theView.findtheme(pntThmName)
  table_pnt=pntTheme.getftab
  field_id=table_pnt.findfield("ID")
  for each rec in table_pnt
    if (table_pnt.returnvalue(field_id,rec)=id_number)then
      msgbox.error("ID number duplicated","WRAP Parameters")
      exit
    end
  end

  pntFtab=pntTheme.getftab
  if(pntFtab.canedit) then
    pntFtab.seteditable(true)
  else
    msgbox.error("Can’t edit point theme.","WRAP Parameters")
    exit
  end
end

’Add new point to theme
theShpFld=pntFtab.findfield("Shape")
theIdFld=pntFtab.findfield("ID")
theTypeFld=pntFtab.findfield("Type")
newRec=pntTheme.getftab.addrecord
pntFtab.setvalue(theShpFld,newRec,pt)
pntFtab.setvalue(TheIdFld,newRec,id_number)
pntFtab.setvalue(theTypeFld, newRec, choise)

’Stop editing and clear tool
pntFtab.seteditable(false)
theTool=nil

exit
```

’ **Script: wrap.addtopo, wrap02.ave**

```
’
’ Description: Adds a topographic map to a view (DRGs), cuts
the edges off and zooms in...
’
’ History: Modified 9/24/99 by Brad Hudgens from original by
JonaFinndis Jonsdottir, CRWR

theVal=self
theView = av.getactivedoc

if (not (theVal.isnull)) then
   theVal2 = _theDRGpath + "/O" + theVal + ".tif".asstring

if (not (file.exists(theVal2.asfilename))) then
  msgbox.info("DRG not found","WRAP Parameters" )
  exit
end

if (file.exists(theVal2.asfilename)) then
            ’ Create the SourceName...
            theSrc = srcname.make(theVal2)

            ’ Use the SourceName to make a theme...
            aTheme = theme.make(theSrc)

            ’ Add the theme to the view...
            theView.addtheme(aTheme)

            ’ Set a new name for the theme...
            aTheme.setname(theVal)

            ’ Change the extent of the DRG, i.e. cut the edges off.
            r = rect.makeempty
            r = r.unionwith(aTheme.returnextent)
bottom1 = r.getbottom
top1 = r.gettop
left1 = r.getleft
right1 = r.getright
height1 = r.getheight
width1 = r.getwidth
heighta = height1*0.105
heightb = height1*0.050
widtha = width1*0.0615
widthb = width1*0.0615

bottom2 = (bottom1 + heighta)
top2 = top1 - heightb
left2 = left1 + widtha
right2 = right1 - widthb
r2 = rect.makeXY(left2, bottom2, right2, top2)
if (r2 <> NIL) then
  aTheme.getimgsrc.setclipextent(r2)
end

            ’ Draw the theme...
            aTheme.setvisible(true)

            ’ Make txmesh unactive
            for each t in theView.getactivethemes.clone
            t.setactive( false )
            end

            aTheme.setactive(true)

            ’ Zoom
```

```
            av.getproject.setmodified(true)
            theThemes = theView.getactivethemes
            r = rect.makeempty
            for each t in theThemes
                        r = r.unionwith(t.returnextent)
            end

 if (r.isempty) then
  return nil
 elseif ( r.returnsize = (0@0) ) then
  theView.getdisplay.panto(r.returnorigin)
 else
  theView.getdisplay.setextent(r.scale(1.1))
 end
   else
            msgbox.warning("File "+theVal2+" not found.","Hot
Link" )
   end
end
```


'Script: wrap.avgcn, wrap03.ave

```
'
'Description: creates average upstream area CN grid from
weighted flow accumulation grid
'
'History: Original by Brad Hudgens, 9/24/99

theView=av.getactivedoc
thethemes=theView.getthemes

theGthemes = list.make
for each theTheme in theThemes
  if(theTheme.getclass.getclassname = "gtheme") then
    theGthemes.add(theTheme)
  end
end
if (theGthemes.count < 3) then
  msgbox.error("Need 3 grids : flow direction, flow
accumulation, and curve number","WRAP Parameters")
  exit
end


fdrGtheme=msgbox.choice(theGthemes,"Select Flow Direction
Grid", "WRAP Parameters")
facGtheme=msgbox.choice(theGthemes,"Select Flow
Accumulation Grid","WRAP Parameters")
cnGtheme=msgbox.choice(theGthemes,"Select Curve Number
Grid","WRAP Parameters")

fdrGrid=fdrGtheme.getgrid
facGrid=facGtheme.getgrid
cnGrid=cnGtheme.getgrid

wtFacGrid=fdrGrid.flowaccumulation(cnGrid)
avgCnGrid=((wtFacGrid+cnGrid)/(facGrid+1))

aFn=fn.make("AvgCN")
avgCnGrid.rename(aFn)
avgCnGtheme=gtheme.make(avgCnGrid)
avgCnGtheme.setname("AvgCN")
theView.addtheme(avgCnGtheme)
```

```
' Script: wrap.avggridbypoly, wrap04.ave
'
' Description:  Given an arbitrary
' polygon coverage, compute the average values for
' gridcells falling within each polygon, add a field
' to the polygon coverage, and copy the average values
' into this field.
'
' History: Modified by Brad Hudgens 9/24/99 from original by
Seann Reed, CRWR

'determine inputs
theProject=av.getproject
theView=av.getactivedoc
availThemes=theview.getthemes

'make a list of themes
polyThemes=list.make
gridThemes=list.make
for each t in availThemes
   if (t.getclass.getclassname <> "GTheme") then
      if (t.getftab.findfield("shape").gettype=#field_shapepoly)
then
         polyThemes.add(t)
      end
   else
      gridThemes.add(t)
   end
end

avgTheme=msgbox.choiceasstring(polyThemes,"Select the
polygon theme","WRAP Parameters")
if (avgTheme = NIL) then
  exit
end

gridTheme=msgbox.choiceasstring(gridThemes,"Select the
Grid","WRAP Parameters")
if (gridTheme = NIL) then
  exit
end

avgFtab=avgTheme.getftab
inGrid=gridtheme.getgrid
avgFields=avgFtab.getfields
zoneField=msgbox.choice(avgFields,"Identify a field with a
unique ID","WRAP Parameters")
if (zoneField=nil) then
   msgbox.info("No zone field selected.  Exiting.","")
   exit
end
outFname=msgbox.input("Enter output field name","WRAP
Parameters","IncAvg")
if (outFname=nil) then
  exit
end
avgFtab.seteditable(true)
if (avgFtab.findfield(outFname)<>nil) then
  msgbox.info("Field named"++outfname++"already exists in
averaging theme","WRAP Parameters")
  exit
end
avgType=msgbox.choiceasstring({"Average","Most Likely
Value"},"Select Average Type","Average")
if (avgType.count=0) then
  msgbox.info("No averaging type selected","WRAP
```

```
Parameters")
  exit
end

'Adding Fields to Polygon Attribute Table
tabOutName="temp.dbf"
tabOutFname=tabOutName.asfilename
outVtab=inGrid.zonalstatstable(avgFtab,prj.makenull,zoneFielc
,false,tabOutFname)
fromField=outVtab.findfield(zoneField.getname)
if (avgType = "Average")  then
   valField=outVtab.findfield("Mean")
elseif (avgtype = "Most Likely Value") then
   valField=outVtab.findfield("Majority")
else
   msgbox.info("You should never see this","WRAP
Parameters")
end
outField=field.make(outFname,valField.gettype,valField.getwic
th,valField.getprecision)
outFieldC=outField.clone
avgFtab.addfields({outFieldC})
'Add Longest Flow Path by joining tables
avgFtab.join(zoneField,outVtab,fromField)
if (avgType = "Average") then
   joinField=avgFtab.findfield("Mean")
elseif (avgType = "Most Likely Value") then
   joinField=avgFtab.findfield("Majority")
else
   msgbox.info("You should never see this.","WRAP
Parameters")
end
for each rec in avgFtab
  joinVal=avgFtab.returnvalue(joinfield,rec)
  avgFtab.setvalue(outFieldC,rec,joinVal)
end

'remove join
avgFtab.unjoinall
avgFtab.seteditable(false)
```

' **Script: wrap.avgpcp, wrap05.ave**

```
'
' Description: creates average upstream precipitation grid
'
' History: Original by Brad Hudgens, 9/24/99

theView=av.getactivedoc
theThemes=theView.getthemes

theGthemes = list.make
for each theTheme in theThemes
  if(theTheme.getclass.getclassname = "gtheme") then
    theGthemes.add(theTheme)
  end
end
if (theGthemes.count < 3) then
  msgbox.error("Need 3 grids : flow direction, flow
accumulation, and precipitation","WRAP Parameters")
  exit
end
```

```
fdrGtheme=msgbox.choice(theGthemes,"Select Flow Direction
Grid", "WRAP Parameters")
facGtheme=msgbox.choice(theGthemes,"Select Flow
Accumulation Grid","WRAP Parameters")
pcpGtheme=msgbox.choice(theGthemes,"Select Precipitation
Grid","WRAP Parameters")

fdrGrid=fdrGtheme.getgrid
facGrid=facGtheme.getgrid
pcpGrid=pcpGtheme.getgrid

wtFacGrid=fdrGrid.flowaccumulation(pcpGrid)
avgPcpGrid=((wtFacGrid+pcpGrid)/(facGrid+1))

aFn=fn.make("AvgPcp")
avgPcpGrid.rename(aFn)
avgPcpGtheme=gtheme.make(avgPcpGrid)
avgPcpGtheme.setname("AvgPcp")
theView.addtheme(avgPcpGTheme)
```

’Script: wrap.burn, wrap06.ave

```
’
’ Description:  Burns a line coverage (streams) into a grid
coverage (DEM)
’
’ History: Modified 9/23/99 by Brad Hudgens from original by
Brian Adams, CRWR

theProject=av.GetProject
theDir=theProject.GetWorkDir
theView = av.GetActiveDoc

’get themes
theThemes = theview.getthemes
if (theThemes.count = 0) then
    msgbox.error("No themes found", "WRAP Parameters")
    exit
end

theFthemes = list.make
for each theTheme in theThemes
  if (theTheme.getclass.getclassname = "ftheme") then
    theFthemes.add(theTheme)
  end
end
if (theFthemes.count = 0) then
  msgbox.error("No coverage themes found","WRAP
Parameters")
  exit
end

theGthemes = list.make
for each theTheme in theThemes
  if(theTheme.getclass.getclassname = "gtheme") then
    theGthemes.add(theTheme)
  end
end
if (theGthemes.count = 0) then
  msgbox.error("No grid themes found","WRAP Parameters")
  exit
end

’select stream network coverage
```

```
lineTheme = msgbox.choice(theFthemes, "Select the Stream
Network","WRAP Parameters")
if (lineTheme = nil) then
  exit
end

’select the DEM
gridTheme = msgbox.choice(theGthemes, "Select the
DEM","WRAP Parameters")
if (gridtheme = nil) then
  exit
end

DEMGrid=gridtheme.GetGrid
idExtent=demGrid.GetExtent
idCellSize=demGrid.GetCellSize

’Convert Line coverage to Grid
lineFtab=lineTheme.GetFtab
’--deselect Ftab--
theBitmap=lineFtab.getselection
theBitmap.clearall
lineFtab.updateselection
unitStreamGrd=grid.makefromftab(lineFtab,prj.MakeNull,nil,{
dCellSize,idExtent})
aFN=theDir.maketmp("UnitStrm","")
unitStreamGrd.Rename(aFN)

’Process DEM
demStream = DEMGrid*unitStreamGrd
theElevation = MsgBox.Input("Enter the arbitrary elevation
rise."+nl+
"This value should be greater than the highest point in the
DEM.","Elevation Rise","5000")
demplus = DEMGrid+theElevation.AsNumber

’Merge the grids
listGrid = {demplus}
outGrid = demStream.merge(listGrid)

’Save and add Burned DEM to view
aFN=fn.make("burndem")
outGrid.rename(aFN)
outTheme = GTheme.make(outGrid)
outTheme.setname("BurnDEM")
theView.addtheme(outTheme)
```

’ **Script: wrap.changeDRGpath, wrap07.ave**

```
’
’ Description: Sets global variable for DRG file path
’
’ History: Original by Brad Hudgens, 9/24/99

_theDRGPath=msgbox.input("Please input the full path name to
the directory containing the DRG files :","WRAP
Parameters","e:/")
exit
```

’ **Script: wrap.cleannet_tool, wrap08.ave**

```
’
’ Description: Corrects topology of a line coverage when an arc
’ is added to the theme and one endpoint is snapped to the
middle
’ of an existing arc.  Splits the existing arc at the intersection
’ with the added arc, creating a regular node at that point
’
’ History: Original by Brad Hudgens, 9/24/99

currSel={}
splitList={}
nodeListA={}
nodeListB={}
lineList={}

theView=av.getactivedoc
theDisplay=av.getactivedoc.getdisplay
theFtheme=theView.getactivethemes.get(0)
theFtab=theFtheme.getFtab
thePolygon=theDisplay.returnuserrect
theFtab.selectbyrect(thePolygon,#VTAB_SELTYPE_NEW)
theShape=theFtab.findfield("shape")
theFtab.seteditable(true)
currSel=theFtab.getselection
theprj=theview.getprojection

count=0

for each rec in theFtab.getselection
  theLine=theFtab.returnvalue(theShape, rec)
  lineList.add(theLine)
  count=count+1
end

if (count<2) then
  msgbox.error("You have selected less than two arcs","WRAP
Parameters")
  exit
end

if (count>2) then
  msgbox.error("You have selected more than two arcs","WRAP
Parameters")
  exit
end

lineA=lineList.Get(0)
lineB=lineList.Get(1)

thePointsA = lineA.asmultipoint.returnprojected(theprj)
thePointsB = lineB.asmultipoint.returnprojected(theprj)

nodeListA.add(thePointsA.aslist.get(0))
nodeListA.add(thePointsA.aslist.get(thePointsA.count-1))

nodeListB.add(thePointsB.aslist.get(0))
nodeListB.add(thePointsB.aslist.get(thePointsB.count-1))

for each node in nodeListA
  if (lineB.contains(node)) then
    splitList=lineB.split(node)
    for each item in splitList
        newRec=theFtab.addrecord
        theFtab.setvalue(theShape, newRec, item)
```

```
    end
    newLineA=lineA.aspolyline
    newRec=theFtab.addrecord
    theFtab.setvalue(theShape, newRec, newLineA)
    theFTab.removerecords(theFtab.getselection.clone)
  end
end

for each node in nodeListB
  if (lineA.contains(node)) then
    splitList=lineA.split(node)
    for each item in splitList
        newRec=theFtab.addrecord
        theFtab.setvalue(theShape, newRec, item)
    end
    newLineB=lineB.aspolyline
    newRec=theFtab.addrecord
    theFtab.setvalue(theShape, newRec, newLineB)
    theFtab.removerecords(theFtab.getselection.clone)
  end
end

theftab.seteditable(false)
```

' Script: wrap.clipgridbypoly, wrap09.ave

```
'
' Description: clips grid theme values to extent of polygon
'
' History: Modified by Brad Hudgens, 9/24/99 from original in
CRWR Raster
'Describe how clipping will occur and allow cancellation
response=msgbox.yesno("The ACTIVE grid will be clipped to
the chosen polygon theme. Continue?","WRAP
Parameters",false)
if (response=nil) then
  exit
end

'Get the active view and check if enough themes exist to
perform operation
theView = av.getactivedoc 'Uses the active view
themeList = theView.getthemes
if (nil = themeList) then
  exit
end
if (themeList.count < 2) then
  msgbox.error("Need at least 2 themes in the View","WRAP
Parameters")
  exit
end

'Use the active grid theme
theGrid=theView.getactivethemes.get(0).getgrid

'Choose the polygon theme
polyList = list.make
for each aTheme in themeList
 if (aTheme.canselect=true) then
   if (aTheme.getFtab.findfield("Shape").gettype =
#FIELD_SHAPEPOLY) then
     polyList.add(aTheme)
   end
```

```
 else
 end
end

thePolyTheme = msgbox.choiceasstring(polyList,"Which
polygon theme is the clipping theme","WRAP Parameters")
if (thePolyTheme=Nil) then
  exit
end
response=msgbox.yesno("Grid theme will be clipped to the
selected features of the clipping theme. If nothing is selected,
the extent of all features in the clipping theme will be used.
Continue?","WRAP Parameters",false)
if (response=false) then
  exit
end

'Get bounds of clipping area as a rectangle
thePolyThmExtent  = thePolyTheme.getselectedextent
if (thePolyThmExtent .isempty) then
  thePolyThmExtent = thePolyTheme.returnextent
end

'Get parameters for the new grid
theFtab = thePolyTheme.getftab
theProj = theView.getprojection
theCell = theGrid.getcellsize
theExtent = theGrid.getextent

ae = theView.getextension(AnalysisEnvironment)
ae.setextent(#ANALYSISENV_VALUE, thePolyThmExtent)
ae.setcellsize(#ANALYSISENV_VALUE, theCell)

' Activate the settings for the analysis envirnonment as returned
' by the above 3 lines of code.
ae.activate

'the actual extraction occurs here
tempGrid =
grid.makefromftab(theFtab,theProj,nil,{theCell,theExtent})
newGrid = (tempGrid.isnull).con (tempGrid, theGrid)

' rename data set
aFn = av.getproject.getworkdir.maketmp("gext", "")
newGrid.rename(aFn)

' check if output is ok
if (newGrid.haserror) then
  return NIL
end

' create a theme
gridThm = theme.make(newGrid.getsrcname)

' set name of theme
gridThm.setname("Extract from " + theGrid.getname)

' add theme to the specifiedView
theView.addtheme(gridThm)

' Resets the analysis environment to the maximum of inputs (i.e.
the default)
aRect = nil
ae = theView.getextension(AnalysisEnvironment)
ae.SetExtent(#ANALYSISENV_MAXOF, aRect)
ae.SetCellSize(#ANALYSISENV_MAXOF, aRect)
```

```
gridThm.invalidate(true)
```

'Script: wrap.dangle_menu, wrap10.ave

```
'
' Description: Identifies all dangling nodes of the active line theme
' within the view extent
'
' History: Modified by Brad Hudgens, 9/24/99 from original by Stepan Kafka
' at ESRI script download site

'Graphic symbol for Dangle Node
sDangle = av.getsymbolwin.getpalette.getlist(#PALETTE_LIST_MARKER).get(1).clone
sDangle.setcolor(color.getred)
sDangle.setsize(6)

'Initializing
theView = av.getactivedoc
theTool=av.getactivegui.gettoolbar.getactive.gettag

cont=msgbox.yesno("This script identifies all dangling nodes in the active theme within the view extent.  It is slow to run on a large view extent.  Do you want to continue?","WRAP Parameters",TRUE)
If (cont=false) then
  exit
end

'Choose output as graphic or theme
modeList={"Theme","Graphics"}
mode=msgbox.choiceasstring(modeList,"Select output method","WRAP Parameters")

'If Theme mode make new theme with name Dangles
If (mode="Theme") then
  theDir=av.getproject.getworkdir
  theFn=fn.merge(theDir.asstring,"Dangles.shp")
  newFtab=ftab.makenew(theFn,point)
  newFields=list.make
  newFields.add(field.make("ID",#field_long,12,0))
  newFtab.addfields(newFields)
  newFtab.seteditable(true)
  shapeFld=newFtab.findfield("Shape")
  idFld=newFtab.findfield("ID")
  theid=1
end

thePrj = theView.getprojection
theSelMode = theView.getselectmode
theView.setselectmode(#GRAPHICS_SELECT_NORMAL)
theTheme = theView.getactivethemes.get(0)
theTable = theTheme.Getftab
D = theView.getdisplay
theShape = theTable.findfield("Shape")
nodeList = {}

'Selecting the shapes
oldSel = theTable.getselection.clone
dExt = D.returnvisextent
```

```
theTheme.selectbyrect(dExt, #VTAB_SELTYPE_NEW)
currSel = theTable.getselection.clone
theTable.setselection(oldSel)

'Vertices drawing and Nodes collecting
D.beginclip
for each rec in CurrSel
  theLines = theTable.returnvalue(theShape,
rec).aspolyline.explode
  for each L in theLines
    thePoints = L.asmultipoint.returnprojected(thePrj)
    nodeList.add(thePoints.aslist.get(0))
    nodeList.add(thePoints.aslist.get(thePoints.count-1))
  end
end

'Nodes processing
allNodes = nodeList.count-1
av.showmsg("Searching nodes...")
av.showstopbutton
while (nodeList.count > 0)
  overPos = 0
  thePoint= nodeList.get(0)
  nodeList.remove(0)
  nodes = nodeList.count-1
  if (av.setstatus((allNodes-nodes)/allNodes*100).not) then
    av.setstatus(100)
    av.showmsg("Cancelled by operator.")
    exit
  end
  C = 0
  while (C <= nodes)
    if (thePoint.intersects(nodeList.get(C))) then
      nodeList.remove(C)
      nodes = nodes - 1
      overPos = overPos + 1
    else
      C = C + 1
    end
  end

  if (overPos < 1) then
    if (mode="Graphics") then
      D.drawpoint(thePoint, sDangle)
    else
      'Add point to theme
      newRec=newFtab.addrecord
      newFtab.setvalue(shapeFld, newRec, thePoint)
      newFtab.setvalue(idFld, newRec, theId)
      theId=theId+1
    end
  end
end

D.endclip

if (mode="Theme") then
  newTheme=ftheme.make(newFtab)
  theView.addtheme(newTheme)
  newFtab.seteditable(false)
end

av.setstatus(100)
av.clearmsg
theView.setselectmode(theSelMode)
theTool=nil
```

```
av.purgeobjects
```

’ Script: wrap.dangle_tool, wrap11.ave

```
’
’ Description: Identifies all dangling nodes of the active line
theme
’ within the view extent
’
’ History: Modified by Brad Hudgens, 9/24/99 from original by
Stepan Kafka
’ at ESRI script download site

’Dangle Node
sDangle =
av.getsymbolwin.getpalette.getlist(#PALETTE_LIST_MARKE
R).get(1).clone
sDangle.setcolor(color.getred)
sDangle.setsize(6)

’Initializing
theView = av.getactivedoc
theTool=av.getactivegui.gettoolbar.getactive.gettag

thePrj = theView.getprojection
theSelMode = theView.getselectmode
theView.setselectmode(#GRAPHICS_SELECT_NORMAL)
theTheme = theView.getactivethemes.get(0)
theTable = theTheme.getftab
D = theView.getdisplay
theShape = theTable.findfield("Shape")
nodeList = {}
```

```
’Selecting the shapes
oldSel = theTable.getselection.clone
dExt = D.returnvisextent
theTheme.selectbyrect(dExt, #VTAB_SELTYPE_NEW)
currSel = theTable.getselection.clone
theTable.setselection(oldSel)

’Vertices drawing and Nodes collecting
D.beginclip
for each rec in currSel
  theLines = theTable.returnvalue(theShape,
rec).aspolyline.explode
  for each L in theLines
    thePoints = L.asmultipoint.returnprojected(thePrj)
    nodeList.add(thePoints.aslist.get(0))
    nodeList.add(thePoints.aslist.get(thePoints.count-1))
  end
end

’Nodes processing
allNodes = nodeList.count-1
av.showmsg("Searching nodes...")
av.showstopbutton
while (nodeList.count > 0)
  overPos = 0
  thePoint= nodeList.get(0)
  nodeList.remove(0)
  nodes = nodeList.count-1
  if (av.setstatus((allNodes-nodes)/allNodes*100).not) then
    av.showstatus(100)
    av.showmsg("Cancelled by operator.")
    exit
  end
```

```
  C = 0
  while (C <= nodes)
    if (thePoint.intersects(nodeList.get(C))) then
      nodeList.remove(C)
      nodes = nodes - 1
      overPos = overPos + 1
    else
      C = C + 1
    end
  end

  if (overPos < 1) then
    D.drawpoint(thePoint, sDangle)
  end
end
D.endclip
av.setstatus(100)
av.clearmsg
theView.setselectmode(theSelMode)
theTool=nil
av.purgeobjects
```

'Script: wrap.dissolve, wrap12.ave

```
'
' Description: dissolves extra polygons created vectorizing
' watersheds
'
' History: Modified by Brad Hudgens, 9/24/99 from original in
CRWR Prepro

theView=av.getactivedoc

theThemes = theView.getthemes
if (theThemes.count = 0) then
    msgbox.error("No themes found", "WRAP Parameters")
    exit
end

theFthemes = list.make
for each theTheme in theThemes
  if (theTheme.getclass.getclassname = "ftheme") then
    theFthemes.add(theTheme)
  end
end
if (theFthemes.count = 0) then
  msgbox.error("No feature themes found","WRAP Parameters")
  exit
end

pTheme=msgbox.choiceasstring(thefthemes,"Select the watershed
polygon theme","WRAP Parameters")
if (pTheme=nil) then
  exit
end

pFtab=pTheme.getftab
if(pFtab.canedit)then
  pFtab.seteditable(true)
end

'Setup Field handles.
pGcode=pFtab.findfield("CP")
if(pGcode=nil)then
  msgbox.error("CP field not found","")
  exit
```

```
tnr=pFtab.getnumrecords
doneDict=dictionary.make(tnr)  'Keep track of the polygons
processed.
for each rec in pFtab
  doneDict.add(rec.clone,0)    '0=not processed, 1=processed.
end
dsvList=list.make              'Holds the polygons to be dissolved.
dsvRecList=list.make           'Holds the dsvRecs.
'DsvList and DsvRecList are sorted with MaxArea ShpV on Top.
(0 indexed)
dDList=list.make               'Holds the records to be deleted after
dissolving.
Cancelled=False
av.showstopbutton
for each rec in pFtab
  cancelled=av.setstatus(rec/tnr*100).not
  if(cancelled)then
    exit
  end
  if(doneDict.get(rec)>0)then
    continue
  end
  doneDict.set(rec.clone,1)
  pGcodeV=pFtab.returnvalue(pGcode,rec)
  dsvList.empty
  dsvRecList.empty
  for each pRec in pFtab
    if(pRec=rec)then
      continue
    end
    pGcodeC=pFtab.returnvalue(pGcode,pRec)
    if(pGcodeV=pGcodeC)then
      if(dsvList.count=0)then  'First time in here, put in the
orgShpV
        orgShpV=pFtab.returnvalue(pShape,rec)
        maxArea=orgShpV.returnarea
        dsvList.add(orgShpV.clone)
        dsvRecList.add(rec.clone)
      end
      cmpShpV=pFtab.returnvalue(pShape,pRec)
      theArea=cmpShpV.returnarea
      if(theArea>maxArea)then
        maxArea=theArea
        dsvList.insert(cmpShpV.clone)  'MaxArea on Top.
        dsvRecList.insert(pRec.clone)
      else
        dsvList.add(cmpShpV.clone)
        dsvRecList.add(pRec.clone)
      end
      doneDict.set(pRec.clone,1)
    end  'if(pGcodeV=pGcodeC)
  end 'for each pRec in PFtab
  if(dsvRecList.count>0)then

av.run("hydro.DemPstDslvMg_diag",{theView,pFtab,pShape,d
svList,dsvRecList,dDList})
  end
end  'for each rec in PFtab
if(dDList.count>0)then
  av.run("hydro.RmvRecsLst",{pFtab,dDList,false})  'PFtab will
be returned Editable(False)
end
av.setstatus(100)
msgbox.error("No grids found","WRAP Parameters")
  exit
end
```

’Script: wrap.fac, wrap13.ave

```
’
’Description: Based on a selected flow-dir
’  grid, construct flow-accumulation grid.
’
’History: Modified by Brad Hudgens 9/23/99 from CRWR
Prepro

theView=av.getactivedoc
thethemes=theView.getthemes

thegthemes = list.make
for each theTheme in theThemes
  if(theTheme.getclass.getclassname = "gtheme") then
    theGthemes.add(theTheme)
  end
end
if (theGthemes.count = 0) then
  msgbox.error("No grids found","WRAP Parameters")
  exit
end

InThm=msgbox.choice(theGthemes,"Select the Flow Direction
Grid","WRAP Parameters")

’Flow accumulation starts here.
g = InThm.getgrid
r = g.flowaccumulation(NIL)

aFN = FN.make("Fac")
r.rename(aFN)

if (r.HasError) then
  msgbox.error("Error in flow accumulation grid","WRAP
Parameters")
  return NIL
end

gthm = GTheme.make(r)
gthm.setname("Fac")
theView.addtheme(gthm)
```

’Script: wrap.fdr, wrap14.ave

```
’
’Description: Based on a selected fill-dem,
’  construct flow-direction grid.
’
’History: Modified by Brad Hudgens 9/23/99 from CRWR
Prepro

theView=av.getactivedoc
theThemes=theView.getthemes

theGthemes = list.make
for each theTheme in theThemes
  if(theTheme.getclass.getclassname = "gtheme") then
    theGthemes.add(theTheme)
  end
end
if (theGthemes.count = 0) then
  msgbox.error("No grids found","WRAP Parameters")
  exit
end
```

```
InThm=msgbox.choice(theGthemes,"Select the Filled
DEM","WRAP Parameters")


'Flow direction starts here.
g=InThm.getgrid
r=g.flowdirection(FALSE)

'rename data set
aFN=FN.make("Fdr")
r.rename(aFN)
if(r.HasError)then
  msgbox.info("Error in Flow Direction Grid","WRAP
Parameters")
  return NIL
end

gthm=GTheme.make(r)
gthm.setname("Fdr")
theView.addtheme(gthm)
```

' **Script: wrap.fdrstreams_mod, wrap15.ave**

```
'
' Description: Defines flow direction stream network with
' correct topology.  As each arc is added, the first intersection is
found.
' The added and existing arcs are split at that point with only the
upstream
' portion of the added arc retained
'
' History: Original by Brad Hudgens, 1/19/99

'Initializing
theView=av.getactivedoc
theThemes=theView.getthemes

demGtheme=msgbox.choice(theThemes, "Select the Filled
DEM", "WRAP Parameters")
fdrGtheme=msgbox.choice(theThemes, "Select the Flow
Direction Grid", "WRAP Parameters")
networkFtheme=msgbox.choice(theThemes, "Select Stream
Network", "WRAP Parameters")

demGrid = demGtheme.getgrid
fdrGrid = fdrGtheme.getgrid
theTable = networkFtheme.getFtab
theShape = theTable.findfield("Shape")
nodeList = {}
fdrList = {}
checkList = {}
splitList={}
splitList3={}
splittheLine={}
nodeLista={}
nodeListb={}

'Create or get FdrNetTest.shp output file
lineThmName = "FdrNetTest.shp"
TheDir=av.getproject.getworkdir
lineFname=FN.merge(TheDir.asstring,"FdrNetTest.shp")

if (theView.findtheme(lineThmName)=nil) then
```

```
   lineFtab=ftab.makenew(lineFname,polyline)
   lineTheme=ftheme.make(lineFtab)
   lineFields=list.make
   lineFields.add(field.make("ID",#field_long,12,0))
   lineFtab.addfields(lineFields)
   theView.addtheme(lineTheme)
   lineTheme.setvisible(true)
else
   lineTheme=theView.findtheme(lineThmName)
   lineFtab=lineTheme.getftab
   linetheme.setvisible(true)
end

'Collect all Nodes in Polyline Network
for each rec in theTable
  theLines = theTable.returnvalue(theShape,
rec).aspolyline.explode
  for each reach in theLines
    thePoints = reach.asmultipoint
    nodeList.add(thePoints.aslist.get(0))
    nodeList.add(thePoints.aslist.get(thePoints.count-1))
  end
end

'Find all dangling nodes and add flowpath for each to
streamlines.shp
theId = 1
elements = 0
theView.seteditabletheme(lineTheme)
theField = lineFtab.findfield("Shape")
theOtherField = lineFtab.findfield("ID")
allNodes = nodeList.count-1
av.showmsg("Working...")
```

```
av.showstopbutton
while (nodeList.count > 0)
  overPos = 0
  thePoint= nodeList.get(0)
  nodeList.remove(0)
  nodes = nodeList.count-1
  if (av.setstatus((allNodes-nodes)/allNodes*100).not) then
    av.aetatatus(100)
    av.showmsg("Cancelled by operator.")
    exit
  end
  C = 0
  while (C <= nodes)
    if (thePoint.intersects(nodeList.get(C))) then
      nodeList.remove(C)
      nodes = nodes - 1
      overPos = overPos + 1
    else
      C = C + 1
    end
  end
  if (overPos < 1) then

    theLine = demGrid.returncostpath(fdrGrid,thePoint)
    'SPLIT LINES ROUTINE
    if ((theLine.isempty).not) then
      if ((elements=0).not) then

        'get all lines that intersect theLine

lineFtab.selectbypolyline(theLine,#VTAB_SELTYPE_NEW)

        for each rec in (lineFtab.getselection)
```

```
 aLine=lineFtab.returnvalue(theField,rec)
 checkList.add(aLine)
end

’ alternate method : convert theLine to multipoint
’ and check each vertex in order with findbypoint
’ to see if it is contained in neighboring arcs

’ another method : just selectbypoint for each
’ vertex and see what is returned

’get all nodes from intersecting lines
for each checkLine in checkList
 checkSeg=checkLine.returndifference(theLine)
 if ((checkSeg.isnull).not) then
   checkPnts=checkSeg.asmultipoint
   nodeLista.add(checkPnts.aslist.get(0))
   NodeLista.add(checkPnts.aslist.get(checkpnts.count-1))
   ’if (checkpnts.isnull) then
     ’msgbox.error("No checkseg!","WP")
     ’exit
   ’end
 end
end

’Keep only nodes that are on theLine
for each node in nodeLista
 if (theLine.contains(node)) then
   nodeListb.add(node)
 end
end

’Find which node is closest to head = split node
```

```
        interpos=100
        for each node in nodeListb
          pos=theLine.pointposition(node)
          if (pos<=interpos) then
            interpos=pos
            splitNode=node
          end
        end

        if (interpos=100) then
          msgbox.error("interpos=100!","WP")
          exit
        end

        if ((splitNode.isnull).not) then
          splitTheLine=theLine.split(splitNode)
          ’if (splitTheLine.isempty) then
            ’splitTheLine=theLine
          ’else
          theNewLine=splitTheLine.get(0)

lineFtab.selectbypoint(splitNode,1,#VTAB_SELTYPE_NEW)
          for each rec in lineFtab.getselection
            workLine=lineFtab.returnvalue(theField, rec)
            splitList=workLine.split(splitNode)
            lineFtab.removerecord(rec)
          end
        else
          msgbox.error("No line found","WRAP Parameters")
          exit
        end

        for each listing in SplitList
```

```
      newRec = lineFTab.addrecord
      lineFtab.setvalue(theField, newRec, listing)
      lineFtab.setvalue(theOtherField, newRec, theId)
      theId = theId + 1
     end

     newRec = lineFtab.addrecord
     lineFtab.setvalue(theField, newRec, theNewLine)
     lineFtab.setvalue(theOtherField, newRec, theId)
     theId = theId + 1
     elements=elements+2

     nodeLista.empty
     nodeListb.empty
     splitTheLine.empty
     splitList.empty
    else
     newRec = lineFtab.addrecord
     lineFtab.setvalue(theField, newRec, theLine)
     lineFtab.setvalue(theOtherField, newRec, theId)
     theId = theId + 1
     elements=elements+1
    end
   end
  end
end

av.setstatus(100)
av.clearmsg
av.getproject.setmodified(true)

lineFtab.seteditable(false)
```



```
' Script: wrap.fdrstreams, wrap16.ave
'
' Description: Traces stream flow path from a flow direction
grid and filled DEM for all the dangling nodes (headwaters)in a
stream network
' The stream network must be clean with no internal dangling
nodes.
'
' History: Created 1/18/99 by Brad Hudgens

'Initializing
theView=av.getactivedoc

'get themes
theThemes = theview.getThemes
if (theThemes.count = 0) then
   msgbox.error("No themes found", "WRAP Parameters")
   exit
end

theFthemes = list.make
for each theTheme in theThemes
  if (theTheme.getclass.getclassname = "ftheme") then
    theFthemes.add(theTheme)
  end
end
if (theFthemes.count = 0) then
  msgbox.error("No feature themes found","WRAP
Parameters")
  exit
end
```

```
theGthemes = list.make
for each theTheme in theThemes
  if(theTheme.getclass.getclassname = "gtheme") then
    theGthemes.add(theTheme)
  end
end
if (theGthemes.count = 0) then
  msgbox.error("No grid themes found","WRAP Parameters")
  exit
end

demGtheme=msgbox.choice(theGthemes,"Select Filled
DEM","WRAP Parameters")
fdrGtheme=msgbox.choice(theGthemes,"Select Flow Direction
Grid","WRAP Parameters")
networkFtheme=msgbox.choice(theFthemes, "Select Stream
Network", "WRAP Parameters")

demGrid=demGtheme.getgrid
fdrGrid=fdrGtheme.getgrid
theTable = networkFtheme.getftab
theShape = theTable.findfield("Shape")
NodeList = {}
dangleList={}
centerList={}
dangleCount=1

'Create or get Fdrstrmnet.shp output file
linethmname = "FdrStrmNet.shp"
theDir=av.getproject.getworkdir
lineFname=FN.merge(theDir.asstring,"FdrStrmNet.shp")

if (theView.findtheme(linethmname)=nil) then

   lineFtab=ftab.makenew(lineFname,polyline)
   lineTheme=ftheme.make(lineFtab)

   'must add at least one field in addition to the shape field
   lineFields=list.make
   lineFields.add(field.make("ID",#field_long,12,0))

   lineFtab.addFields(lineFields)
   theView.addTheme(lineTheme)

   lineTheme.setvisible(true)
   lineFtab.seteditable(true)

else

   lineTheme=theView.findtheme(lineThmname)
   lineFtab=lineTheme.getftab

   lineTheme.setvisible(true)
   lineFtab.seteditable(true)
end

'make Ftab for headwater nodes
interFn=FN.make("headwatr")
interFtab=ftab.makenew(interfn,point)

inFlds=list.make
inFlds.add(field.make("ID",#field_long,12,0))

interFtab.addfields(inFlds)
interFtab.seteditable(true)
```

```
'Collect all Nodes in Polyline Network
for each rec in theTable
  theLines = theTable.returnvalue(theShape,
rec).aspolyline.explode
  for each reach in theLines
    thePoints = reach.asmultipoint
    if (thePoints.isnull.not) then
      nodeList.add(thePoints.aslist.get(0))
      nodeList.add(thePoints.asList.get(thePoints.count-1))
    end
  end
end

'Find all dangling nodes and add flowpath for each
interShapeFld=interFtab.findfield("shape")
interIdFld=interFtab.findfield("ID")
theId = 1
allNodes = nodeList.count-1
av.showmsg("Processing Nodes...")
av.showstopbutton
while (nodeList.count > 0)

  overPos = 0
  thePoint= nodeList.get(0)
  nodeList.remove(0)
  nodes = nodeList.count-1
  if (av.setstatus((allNodes-nodes)/allNodes*100).not) then
    av.setstatus(100)
    av.showmsg("Cancelled by operator.")
    exit
  end
  C = 0
  while (C <= nodes)
    if (thePoint.intersects(nodeList.get(C))) then
      nodeList.remove(C)
      nodes = nodes - 1
      overPos = overPos + 1
    else
      C = C + 1
    end
  end
  if (overPos < 1) then
    'add thePoint to intermediate Ftab
    newRec=interFtab.addrecord
    interFtab.setvalue(interShapeFld, newRec, thePoint)
    interFtab.setvalue(interIdFld, newRec, dangleCount)
    dangleCount=dangleCount+1
  end
  av.setstatus((allNodes-nodes)/allNodes*100)
end

idCellSize=demGrid.getcellsize
idExtent=demGrid.getextent

'center points by making interFtab into grid
pntsGrid=grid.makefromftab(interFtab,prj.makenull,interIdFld,
idCellSize,idExtent})

centerFTab=pntsGrid.aspointftab("Centered.shp".asfilename,pr
.makenull)
centerFtab.seteditable(true)
centerFtab.addfields(inflds)

av.showmsg("Building Lines...")
index=0
centrFld=centerFtab.findfield("shape")
```

```
for each center in centerFtab
  progress=index/dangleCount*100
  av.setstatus(progress)
  theNode=centerFtab.returnvalue(centrFld, center)
  theCellValue=demGrid.cellvalue(theNode, prj.makenull)
  if ((theCellValue.isnull).not) then
    theLine = demGrid.returncostpath(fdrGrid,theNode)
    lineFtab.begintransaction
    theField = lineFTab.findfield("Shape")
    theOtherField = lineFTab.findfield("ID")
    rec = lineFTab.addrecord
    lineFtab.setvalue(theField, rec, theLine)
    lineFtab.setvalue(theOtherField, rec, theId)
    lineFtab.endtransaction
    theId = theId + 1
    index=index+1
  end
end

av.setstatus(100)
av.clearmsg
av.getproject.setmodified(true)

lineFtab.seteditable(false)
```

’ **Script: wrap.filldem, wrap17.ave**

```
’
’Description: Fills sinks on an user specified DEM.
’
’History: modified by Brad Hudgens 9/23/99 from CRWR
Prepro

theView=av.getactivedoc
thethemes=theView.getthemes

theGthemes = list.make
for each theTheme in theThemes
  if(theTheme.getclass.getclassname = "gtheme") then
    theGthemes.add(theTheme)
  end
end
if (theGthemes.count = 0) then
  msgbox.error("No grids found","WRAP Parameters")
  exit
end

inThm=msgbox.choice(theGthemes,"Select the DEM","WRAP
Parameters")

’fill sinks in Grid until they are gone
elevGrd=inThm.getgrid

tmpGrd=elevGrd*1

sinkCount=0
numSinks=0
while (TRUE)
  flowDirGrid=tmpGrd.flowdirection(FALSE)
  sinkGrid=flowDirGrid.sink
  if (sinkGrid.GetVTab=NIL) then
    ’check for errors
    if (sinkGrid.HasError) then return NIL end
```

```
    sinkGrid.buildVAT
  end
  'check for errors
  if (sinkGrid.haserror) then return NIL end
  if (sinkGrid.getVTab <> NIL) then
    theVTab=sinkGrid.getvTab
    numClass=theVTab.getnumrecords

newSinkCount=theVTab.returnvalue(theVTab.findfield("Count
"),0)
  else
    numClass=0
    newSinkCount=0
  end
  if (numClass < 1) then
    break
  elseif ((numSinks=numClass) and
(sinkCount=newSinkCount)) then
    break
  end
  waterGrid=flowDirGrid.watershed(sinkGrid)
  zonalFillGrid=waterGrid.zonalfill(tmpGrd)
  fillGrid=(tmpGrd <
(zonalFillGrid.isnull.Con(0.asgrid,zonalFillGrid))).con(zonalFil
Grid,tmpGrd)
  tmpGrd=fillGrid
  numSinks=numClass
  sinkCount=newSinkCount
end

aFN=FN.make("Filldem")
tmpGrd.rename(aFN)
theGTheme=GTheme.make(tmpGrd)    'create a theme
theGTheme.setname("FillDEM")     'set name of theme
theView.addtheme(theGTheme)      'add theme to the view
```

'**Script: wrap.mergethemes, wrap18.ave**

```
'
'Description: Merges two or more themes of the same feature
class.  The fields in the first theme selected are
'  copied to the output shapefile
'
'History: Modified 9/23/99 by Brad Hudgens from original by
Christine Dartinegauve, CRWR

theView=av.GetActiveDoc
theThemes=theView.GetThemes

if (theThemes.Count<2) then
   MsgBox.Error("Must have at least two themes in a view to
   merge.","")
    exit
end

themesToMerge=List.Make
while (true)
    t=MsgBox.Choice(theThemes,"Choose themes in view to
merge:"+NL+"(Click Cancel to end):","WRAP Parameters")
    if (t<>Nil) then
        themesToMerge.Add(t)
    else
        break
```

```
    end
end

if ((themestoMerge=Nil) or (themesToMerge.Count<2)) then
  MsgBox.Error("Not enough themes to merge.","")
  exit
end

checkType=themesToMerge.Get(0).GetFTab.FindField("Shape
").GetType
for each i in 1..(themesToMerge.Count-1)
    t=themesToMerge.Get(i)
    if (checkType<>t.GetFtab.FindField("Shape").GetType) then
        MsgBox.Error("Theme feature type mismatch -- unable to
merge.","")
        exit
    end
end

outFName=av.GetProject.MakeFileName("theme","shp")
outFname=FileDialog.Put(outFname,"*.shp","Output Merged
Shapefile")
if (outFName=Nil) then
    exit
end

fieldList=List.Make
for each f in themesToMerge.Get(0).GetFTab.GetFields
    if (f.GetName="Shape") then
        continue
    else
        fCopy=f.Clone
        fieldList.Add(fCopy)
```



```
    end
end

shapeType=themesToMerge.Get(0).GetFTab.FindField("Shape
").GetType
if (shapeType=#FIELD_SHAPELINE) then
    outClass=POLYLINE
elseif (shapeType=#FIELD_SHAPEMULTIPOINT) then
    outClass=MULTIPOINT
elseif (shapeType=#FIELD_SHAPEPOINT) then
    outClass=POINT
elseif (shapeType=#FIELD_SHAPEPOLY) then
    outClass=POLYGON
else
    MsgBox.Error("Invalid shape field type.","")
    exit
end
mergeFTab=FTab.MakeNew(outFName,outClass)

if (fieldList.Count>0) then
    mergeFTab.AddFields(fieldList)
end

for each t in themesToMerge
    av.ShowMsg("Merging"++t.GetName)
    inFTab=t.GetFTab
    if (inFTab.GetSelection.Count=0) then

        theRecordsToMerge=inFTab
        numRecs=inFTab.GetNumRecords
    else
        theRecordsToMerge=inFTab.GetSelection
        numRecs=theRecordsToMerge.Count
```

```
    end
    for each rec in theRecordsToMerge
        av.SetStatus((rec/numRecs)*100)
        newRec=mergeFTab.Addrecord
        inField=inFTab.FindField("Shape")
        outField=mergeFTab.FindField("Shape")

    mergeFTab.SetValue(outField,newrec,inFTab.ReturnValue(i
nField,rec))
        if (fieldList.Count>0) then
            for each f in fieldList
                fName=f.GetName
                inField=inFTab.FindField(fName)
                if (inField<>Nil) then
                    outField=mergeFTab.FindField(fName)
                    aValue=inFTab.ReturnValue(inField,rec)
                    mergeFTab.SetValue(outField,newRec,aValue)
                end
            end
        end
    end
end

av.ClearMsg
av.ClearStatus

if (MsgBox.YesNo("Add shapefile as theme to view?","WRAP
Parameters",true).Not)then
    exit
end

viewList={}
for each d in av.GetProject.GetDocs
    if (d.Is(View)) then
        viewList.Add(d)
    end
end

viewList.Add("")
addToView=MsgBox.ListAsString(viewList,"Add Theme
to:","WRAP Parameters")

if (addToView<>Nil) then
    if (addToView="") then
        addToView=View.Make
        addToView.GetWin.Open
    end

    mergeTheme=FTheme.Make(mergeFTab)
    addToView.AddTheme(mergeTheme)

    addToView.GetWin.Activate
end
```

’**Script: wrap.network, wrap19.ave**

```
’
’Description: Run on snapped control point theme.  Connects
each
’control point to next downstream control point.  Adds
downstream
’CP field to snapped control point theme and outputs line theme
’showing connectivity
```

```
'
' History: Original by Brad Hudgens, 9/24/99

theView = av.getactivedoc
av.showstopbutton
dsList={}
theDsArcId=0
totCount=0

'get themes
theThemes = theView.getthemes
if (theThemes.count = 0) then
    msgbox.error("No themes found", "WRAP Parameters")
    exit
end

theFthemes = list.make
for each theTheme in theThemes
  if (theTheme.getclass.getclassname = "ftheme") then
    theFthemes.add(theTheme)
  end
end
if (theFthemes.count = 0) then
  msgbox.error("No coverage themes found","WRAP
Parameters")
  exit
end

'select snapped control point coverage
cpTheme = msgbox.choice(theFthemes, "Select the Snapped
Control Point Coverage","WRAP Parameters")
if (cpTheme = nil) then
  exit
end

'select the stream network
strTheme = msgbox.choice(theFthemes, "Select the Stream
Network","WRAP Parameters")
if (strTheme = nil) then
  exit
end

cpFtab = cpTheme.getftab
if (cpFtab = nil) then
    msgbox.error("Can't open control point coverage","WRAP
Parameters")
    exit
end
cpShapeFld = cpFtab.findfield("shape")
cpIdFld = cpFtab.findfield("ID")
cpArcIdFld = cpFtab.findfield("ArcID")
cpPcntFld = cpFtab.findfield("distance")

'make ds cp field
cpFtab.seteditable(true)
newFields=list.make
newFields.add(field.make("DsCP",#field_long,12,0))
cpFtab.addfields(newFields)
cpDsFld=cpFtab.findfield("DsCP")

for each countRec in cpFtab
  totCount=totCount+1
end

strFtab = strTheme.getftab
if (strFtab = nil) then
```

```
    msgbox.error("Can’t open stream network coverage","WRAP
Parameters")
    exit
end
strShapeFld = strFtab.findfield("shape")
strArcIdFld = strFtab.findfield("ArcID")
dsArcIdFld = strFtab.findfield("DSArcID")

theNewFn = fn.make("network")
netFtab = ftab.makenew(thenewfn, polyline)
theIdFld = field.make("Id", #FIELD_decimal,8,0)
netFtab.addfields({theIdFld})

netFtab.seteditable(true)
netShapeFld = netFtab.findfield("shape")
netIdFld = netFtab.findfield("Id")
theId=0
checkList={}
for each rec in cpFtab
  progress=theId/totCount*100
  av.setstatus(progress)
  thePnt = cpFtab.returnvalue(cpShapeFld, rec)
  currArc = cpFtab.returnvalue(cpArcIdFld, rec)
  currPcnt = cpFtab.returnvalue(cpPcntFld, rec)
  foundnext = false

  ’check for d/s point on same arc
   checkDist=101
   for each pntRec in cpFtab
     pntArcId = cpFtab.returnvalue(cpArcIdFld, pntRec)
     pntPcnt = cpFtab.returnvalue(cpPcntFld, pntRec)
     if ((pntArcId = currArc) and (pntPcnt > currPcnt)) then
       foundnext=true
       separation=pntPcnt-currPcnt
       if (separation < checkDist) then
         checkDist = separation
         nextCp = cpFtab.returnvalue(cpShapeFld, pntRec)
         nextCpId = cpFtab.returnvalue(cpIdFld, pntRec)
       end
     end
   end

while (foundnext = false)

  ’find next ds arc
   for each lineRec2 in strFtab
     theArcId = strFtab.returnvalue(strArcIdFld, lineRec2)
     if (theArcId = currArc) then
        theDsArcId = strFtab.returnvalue(dsArcIdFld, lineRec2)
        dsArc = strFtab.returnvalue(strShapeFld, lineRec2)
     end
   end

  ’if dsArcId = 0 then ds cp = outlet
   if (theDsArcId = 0) then
     vertices = dsArc.asmultipoint
     theOutlet = vertices.aslist.get(vertices.count-1)
     nextCp = theOutlet
     nextCpId = 0
     foundnext = true
   end

  ’check for cps on d/sarc
  if (foundnext = false) then
    mark=100
    for each pntRec2 in cpFtab
```

```
      pntArcId2 = cpFtab.returnvalue(cpArcIdFld, pntRec2)

      if (pntArcId2 = theDsArcId) then
        foundnext = true
        pcnt2=cpFtab.returnvalue(cpPcntFld, pntRec2)
        if (pcnt2<=mark) then
          mark=pcnt2
          nextCp=cpFtab.returnvalue(cpShapeFld, pntRec2)
          nextCpId=cpFtab.returnvalue(cpIdFld, pntRec2)
        end
      end
    end
  end
  currArc = theDsArcId
 end

 theLine = polyLine.make({{thePnt, nextCp}})
 newRec = netFtab.addrecord
 netFtab.setvalue(netShapeFld, newRec, theLine)
 netFtab.setvalue(netIdFld, newRec, theId)
 cpFtab.setvalue(cpDsFld, rec, nextCpId)
 theId=theId+1
end

cpFtab.seteditable(false)
netFtab.seteditable(false)
newTheme = ftheme.make(netFtab)
newTheme.setname("network")
theView.addtheme(newTheme)

av.clearstatus
```



```
' Script: wrap.parameters_menu, wrap20.ave
'
' Description: returns parameter values from parameter grids for
' each control point
'
' History: Original by Brad Hudgens, 9/24/99

theView = av.getactivedoc
theDir=av.getproject.getworkdir.asstring
theDisplay=theView.getdisplay
smsg="WRAP Parameters"

if ((_facThmNm=nil) or (_cnThmNm=nil) or
(_pcpThmNm=nil) or (_flowlThmNm=nil)) then
  msgbox.info("Set the parameter grid theme names in the
WRAP Tools menu",smsg)
  exit
end

facThm=theView.findtheme(_facThmNm)
if (facThm=nil) then
  msgbox.info("Flow accumulation theme not found",smsg)
  exit
end

cnThm=theView.findtheme(_cnThmNm)
if (cnThm=nil) then
  msgbox.info("Curve Number theme not found",smsg)
  exit
end

pcpThm=theView.findtheme(_pcpThmNm)
```

```
if (pcpThm=nil) then
  msgbox.info("Precipitation theme not found",smsg)
  exit
end

if (_flowlThmNm <> "none") then
  flowlThm=theView.findtheme(_flowlThmNm)
  if (flowlThm=nil) then
    msgbox.info("Flow length theme not found",smsg)
    exit
  end
end

'Get parameter grids
facGrid=facThm.getgrid
if (facGrid.haserror) then
  msgbox.info("Error in flow accumulation grid", smsg)
  exit
end

avgCnGrid=cnThm.getgrid
if (avgCnGrid.haserror) then
  msgbox.info("Error in curve number grid", smsg)
  exit
end

avgPcpGrid=pcpThm.getgrid
if (avgPcpGrid.haserror) then
  msgbox.info("Error in precipitation grid", smsg)
  exit
end

if (_flowlThmNm <> "none") then
  flowlGrid=flowlThm.getgrid
  if (flowlGrid.haserror) then
    msgbox.info("Error in flow length grid", smsg)
    exit
  end
end

theCellSize = facGrid.getcellsize

'get themes
theThemes = theView.getThemes
if (theThemes.count = 0) then
    msgbox.error("No themes found",smsg)
    exit
end

theFthemes = list.make
for each theTheme in theThemes
  if (theTheme.getclass.getclassname = "ftheme") then
    theFthemes.add(theTheme)
  end
end
if (theFthemes.count = 0) then
  msgbox.error("No feature themes found",smsg)
  exit
end

'select control point coverage
theCpTheme = msgbox.choice(theFthemes, "Select the Control
Point coverage",smsg)
if (theCpTheme = nil) then
  exit
end
```

```
cpFtab = theCpTheme.getftab
if (cpftab = nil) then
    msgbox.error("Can't open control point coverage",smsg)
    exit
end

issnap=msgbox.yesno("Are you using a snapped CP
coverage?",smsg,true)

theNewFn = fn.make(theDir+"parameters")
pFtab = ftab.makenew(theNewFn, point)
theIdField = field.make("Id", #FIELD_FLOAT, 12, 0)
theTypeField = field.make("Type", #Field_VChar, 20, 0)
theFacField = field.make("DemFac", #FIELD_FLOAT, 20, 0)
theAreaField = field.make("Area(sq.mi.)", #FIELD_FLOAT,
20, 4)
theAvgCnField = field.make("AvgCN", #FIELD_FLOAT, 10,
2)
theAvgPcpField = field.make("AvgPrecip", #FIELD_FLOAT,
10, 2)
theFlowlField = field.make("FlowLength", #FIELD_FLOAT,
20, 2)
pFtab.addfields({theIdField, theTypeField, theFacField,
theAreaField, theAvgCnField, theAvgPcpField, theFlowlField})
pFtab.seteditable(true)

if (issnap) then
  theDsCpFld =field.make ("DsCP", #FIELD_LONG, 12,0)
  pFtab.addfields({theDsCpFld})
end

theCpShapeField = cpFtab.findfield("shape")
theCpIdField = cpFtab.findfield("id")
theCpTypeField = cpFtab.findfield("type")
if (issnap) then
  theCpDsFld = cpFtab.findfield("DsCP")
end

thepShapeField = pFtab.findfield("shape")
thepIdField = pFtab.findfield("id")
thepTypeField = pFtab.findfield("type")
if (issnap) then
  theptDsFld = pFtab.findfield("DsCP")
end
thepFacField = pFtab.findfield("DemFac")
thepAreaField = pFtab.findfield("Area(sq.mi.)")
thepCnField = pFtab.findfield("AvgCN")
thepPcpField = pFtab.findfield("AvgPrecip")
thepFlowField = pFtab.findfield("FlowLength")

cnt=0
for each item in cpFtab
  cnt=cnt+1
end

av.showmsg("Building parameters...")
indx=0
for each rec in cpFtab

  progress=((indx/cnt)*100)
  av.setstatus(progress)

  thePoint = cpFtab.returnvalue(theCpShapeField, rec)
  theId = cpFtab.returnvalue(theCpIdField, rec)
  theType = cpFtab.returnvalue(theCpTypeField, rec)
  if (issnap) then
```

```
    theDsCp = cpFtab.returnvalue(theCpDsFld, rec)
  end

  newRec = pFtab.addrecord

  pFtab.setvalue(thepShapeField,newRec,thePoint)
  pFtab.setvalue(thepIdField,newRec,theId)
  pFtab.setvalue(thepTypeField,newRec,theType)
  if (issnap) then
    pFtab.setvalue(theptDsFld, newRec, theDsCp)
  end

  theFacValue = facGrid.cellvalue(thepoint,prj.makenull)
  pFtab.setvalue(thepFacField,newRec,theFacValue)

  theArea = theCellSize^2*theFacValue*0.000000386102
  pFtab.setvalue(thepAreaField,newRec,theArea)

  theCnValue = avgCnGrid.cellvalue(thePoint,prj.makenull)
  pFtab.setvalue(thepCnField,newRec,theCnValue)

  thePcpValue = avgPcpGrid.cellvalue(thePoint,prj.makenull)
  pFtab.setvalue(thepPcpField,newRec,thePcpValue)

  if (_flowlThmNm <> "none") then
    theFlowlValue = flowlGrid.cellvalue(thePoint,prj.makenull)
  else
    theFlowlValue = 0
  end
  pFtab.setvalue(thepFlowField,newRec,theFlowlValue)
  indx=indx+1

end

av.setstatus(100)
pFtab.seteditable(false)
pTheme = ftheme.make(pFtab)
pTheme.setname("Parameters")
theView.addtheme(pTheme)
```

’ **Script: wrap.parameters_tool, wrap21.ave**

```
’
’ Description: returns parameter values from parameter grids for
’ each control point
’
’ History: Original by Brad Hudgens, 9/24/99

theView = av.getactivedoc
smsg="WRAP Parameters"
theDisplay=theView.getdisplay

if ((_facThmNm=nil) or (_cnThmNm=nil) or
(_pcpThmNm=nil) or (_flowlThmNm=nil)) then
  msgbox.info("Set the parameter grid theme names in the
WRAP Tools menu",smsg)
  exit
end

facThm=theView.findtheme(_facThmNm)
if (facThm=nil) then
  msgbox.info("Flow accumulation theme not found",smsg)
  exit
end
```

```
cnThm=theView.findtheme(_cnThmNm)
if (cnThm=nil) then
  msgbox.info("Curve Number theme not found",smsg)
  exit
end

pcpThm=theView.findtheme(_pcpThmNm)
if (pcpThm=nil) then
  msgbox.info("Precipitation theme not found",smsg)
  exit
end

if (_flowlThmNm <> "none") then
  flowlThm=theView.findtheme(_flowlThmNm)
  if (flowlThm=nil) then
    msgbox.info("Flow length theme not found",smsg)
    exit
  end
end

’Get parameter grids
facGrid = facThm.getgrid
if (facGrid.haserror) then
  msgbox.info("Error in flow accumulation grid", smsg)
  exit
end

avgCnGrid=cnThm.getgrid
if (avgCnGrid.haserror) then
  msgbox.info("Error in curve number grid", smsg)
  exit
end

avgPcpGrid = pcpThm.getgrid
if (avgPcpGrid.haserror) then
  msgbox.info("Error in precipitation grid", smsg)
  exit
end

if (_flowlThmNm <> "none") then
  flowlGrid = flowlThm.getgrid
  if (flowlGrid.haserror) then
    msgbox.info("Error in flow length grid", smsg)
    exit
  end
end

theCellSize = facGrid.getcellsize

thePoint=theDisplay.returnuserpoint

theFacValue = facGrid.cellvalue(thePoint,prj.makenull)
theArea = theCellSize^2*theFacValue*0.000000386102
theCnValue = avgCnGrid.cellvalue(thePoint,prj.makenull)
thePcpValue = avgPcpGrid.cellvalue(thePoint,prj.makenull)
if (_flowlThmNm <> "none") then
  theFlowlValue = flowlGrid.cellvalue(thePoint,prj.makenull)
else
  theFlowlValue="none"
end

msgbox.report("Flow accumulation :
"+theFacValue.asstring+NL+"Area (sq.mi.) :
"+theArea.asstring+NL+"Average curve number :
"+theCnValue.asstring+NL+"Average mean annual
```

```
precipitation : "+thePcpValue.asstring+NL+"Flow length :
"+theFlowlValue.asstring,smsg)
exit
```

```
'Script: wrap.resample, wrap22.ave
'
'Description: Resamples a grid to user-specified cell size.
'
'History: Modified by Brad Hudgens 9/24/99 from original by
'Brent L. Brock, Dept. of Agronomy, Kansas State Univ.

'test if Spatial Analyst is loaded
test=extension.find("Spatial Analyst")
if (test=NIL) then
msgbox.error("You must have the spatial analyst extension
loaded","WRAP Parameters")
 return(nil)
end

theView = av.getactivedoc

'get active gTheme
theTheme = theView.getactivethemes.get(0)
theExt = theTheme.getclass.getclassname
if (theExt <> "Gtheme") then
  msgbox.error("The Selected Theme Is Not A Grid", "WRAP
Parameters")
  return(nil)
end
theGrid = theTheme.getgrid
theCellSize = theGrid.getcellsize.asstring

'display input box to get cell size and resampling method
information.
defaultString = theCellSize
theSize = msgbox.input("Enter Output Cell Size", "WRAP
Parameters", defaultstring)
if (theSize = NIL) then
  return(nil)
end

aCellSize = theSize.asnumber
aList = {"Nearest Neighbor","Bilinear Interpolation","Cubic
Convolution"}
for each s in aList
   s.setName(s)
end
theSampMethod = msgbox.choice ( aList,"Resampling
Method", "ResampleGrid")

if (theSampMethod = aList.get(0)) then
  aGridResTypeEnum = #GRID_RESTYPE_NEAREST
elseif (theSampMethod = aList.get(1)) then
  aGridResTypeEnum = #GRID_RESTYPE_BILINEAR
elseif (theSampMethod = aList.get(2)) then
  aGridResTypeEnum = #GRID_RESTYPE_CUBIC
else
  return(nil)
end

'create a theme with resampled data
theGtheme = gtheme.make(theGrid.resample (aCellSize,
aGridResTypeEnum))
```

```
theGtheme.setname("Resampled"++theTheme.GetName)
theView.addtheme(theGtheme)
```

’Script: wrap.setcpthemes, wrap23.ave

```
’
’Description: Defines global variables of control point themes
for use by the add
’and add snapped control point tools
’
’History: Original 9/24/99 by Brad Hudgens

theThemes=list.make
labelList=list.make
defaultList=list.make

labelList={"Control Points","Snapped Control Points"}
defaultList={"ControlPoints","SnapCPs"}

theThemes=msgbox.multiinput("Input the CP Tool Theme
Names :","WRAP Parameters", labelList, defaultList)

_cpThm=theThemes.get(0)
if (_cpThm=nil) then
  msgbox.error("No Control Point Theme","")
  exit
end

_snapCpThm=theThemes.get(1)
if (_snapCpThm=nil) then
  msgbox.error("No Snapped Control Point Theme","")
  exit
end
exit
```

’Script: wrap.setgridthemes, wrap24.ave

```
’
’Description: Defines global variables of control point themes
for use by the add
’and add snapped control point tools
’
’History: Original 9/24/99 by Brad Hudgens

theThemes=list.make
labelList=list.make
defaultList=list.make
smsg="WRAP Parameters"

labelList={"Flow Accumulation","Average Curve
Number","Average Precipitation","Flow Length"}
defaultList={"facalb","acnalb","apcalb","none"}

theThemes=msgbox.multiinput("Input the parameter grid theme
names.  If flow length is not used, enter ’none”",smsg, labelList,
defaultList)

_facThmNm=theThemes.get(0)
if (_facThmNm=nil) then
  msgbox.error("No flow accumulation theme name
entered",smsg)
  exit
```

```
end

_cnThmNm=theThemes.get(1)
if (_cnThmNm=nil) then
  msgbox.error("No average curve number theme name
entered",smsg)
  exit
end

_pcpThmNm=theThemes.get(2)
if (_pcpThmNm=nil) then
  msgbox.error("No average precipitation theme name
entered",smsg)
  exit
end

_flowlThmNm=theThemes.get(3)
if (_flowlThmNm=nil) then
  msgbox.error("No flow length theme name entered",smsg)
  exit
end
exit
```

'**Script: wrap.snapcp_menu, wrap25.ave**

```
'
'Description: Snaps points in point theme onto selected line
theme.
' Points that cannot be snapped are selected (highlighted in the
original
' point theme.  Arcs for snapping are found by FindByPoint
function, which locates features
' within 3 screen pixels of the point.  To make sure arcs can be
found, the view display
' must be zoomed out well beyond the extent of the line theme.
'
'History: Modified 9/23/99 by Brad Hudgens from original by
Richard Gu, CRWR

ID="ID"
factor=1
snap_distance=msgbox.input("Enter a snapping tolerance (in
coverage units):","Wrap Parameters","1000")
sMsg="Creating Snapped Point Coverage"
av.getproject.setmodified(true)
theView = av.getactivedoc

'get themes
theThemes = theView.getthemes
if (theThemes.count = 0) then
    msgbox.error("No themes found", "WRAP Parameters")
    exit
end

theFthemes = list.make
for each theTheme in theThemes
  if (theTheme.getclass.getclassname = "ftheme") then
    theFthemes.add(theTheme)
  end
end
if (theFthemes.count = 0) then
  msgbox.error("No feature themes found","WRAP
Parameters")
  exit
```

```
end

problemList=list.make


’select themes
lineThm=msgbox.choiceasstring(theFthemes, "Select a line
theme", "WRAP Parameters")
if (lineThm=nil) then
  msgbox.info("No line theme has been selected.","")
  exit
end

pntThm=msgbox.choiceasstring(theFthemes, "Select a point
theme", "WRAP Parameters")
if (PntThm=nil) then
  msgbox.info("No point theme has been selected.","")
  exit
end

pntWorkList=List.make
pntFtab=pntThm.getftab
pntFtab.seteditable(true)

newThmName="SnapCPs"
theDir=av.getproject.getworkdir
newFilename=FN.merge(thedir.asstring,newThmName)

newFtab=ftab.makenew(newFilename,point)
newThm=ftheme.make(newFtab)

pntFields=pntFtab.getfields
newFields=pntFields.deepclone
```

```
’get rid of extra Shape field
newFields.remove(0)

newFtab.addFields(newFields)
theView.addtheme(newThm)
newFtab.seteditable(true)

pntFld=pntFtab.findfield("Shape")
newPntFld=newFtab.findfield("Shape")

idFld=pntFtab.findfield(ID)
newIdFld=newFtab.findfield(ID)

typeFld=pntFtab.findfield("Type")
newTypeFld=newFtab.findfield("Type")

arcIdFld=field.make("ArcID",#Field_Long,12,0)
pcntFld=field.make("distance",#Field_Long,4,0)
newFtab.addFields({arcIdFld,pcntFld})

for each rec in pntFtab
  pntWorkList.add(rec.clone)
end

total=pntWorkList.count
lmt_work=total-1

rTheme=lineThm
rFtab=rTheme.getftab
rShape=rFtab.findfield("Shape")
rArcId=rFtab.findfield("ArcID")

av.showmsg("Snapping control points...")
```

```
for each item in 0..lmt_work
  thePntRec=pntWorkList.get(item)
  inPnt=pntFtab.returnvalue(pntFld, thePntRec)
  inPntType=pntFtab.returnvalue(typeFld, thePntRec)

  if(inPnt=nil)then
    msgbox.info("No point is selected","")
    exit
  end

  theFtab=lineThm.getftab

’find neighboring arcs
recs=rTheme.findbypoint(inPnt)
theShpV=nil

if(recs.isempty.not)then
  distance=10000
  for each lnRec in recs
    rShpV=rFtab.returnvalue(rShape,lnRec)
    rArcV=rFtab.returnvalue(rArcId,lnRec)
    dist=inPnt.distance(rShpV)
    if(dist<distance)then
      distance=dist
      theShpV=rShpV
      theArcV=rArcV
    end
  end
  tempPnt=inPnt.clone

FOUND=temppnt.snap(theshpV,SNAP_DISTANCE.asnumber)
  if(FOUND=true)then
    newpnt=temppnt
  else
    thePntV=inPnt
    theShpV=rShpV
    theArcV=rArcV
    pntList=theShpV.asmultipoint.aslist
    ccx=thePntV.getX
    ccy=thePntV.getY
    cLength=0.0
    distList=list.make  ’Dists between each potential snap point
and original point.
    nPntList=list.make  ’Potential snap-to points.
    cLenList=list.make  ’Dists between from node to each
potential snap-to points.
    if(pntList.count=2)then
      aax=pntList.get(0).getX
      aay=pntList.get(0).getY
      bbx=pntList.get(1).getX
      bby=pntList.get(1).getY
      tLength=(((bbx-aax)^2)+((bby-aay)^2))^(0.5)
      AC=((bbx-aax)*(ccx-aax))+((bby-aay)*(ccy-aay))
      cLength=AC/tLength  ’A.C=A.abs*C.abs*Cos(AC),
Clength=C.abs*Cos(AC), A.abs=TLength
      newX=aax+((bbx-aax)*(cLength/tLength))
      newY=aay+((bby-aay)*(cLength/tLength))
      newPnt=point.make(newX,newY)
      pFound=true
    else
      pCnt=pntList.count-2
      pFound=false
      ’Start computation loop
       oldAC=nil
       tLength=0.0
       for each idx in 0..pcnt
```

```
        aax=pntList.get(idx).getX
        aay=pntList.get(idx).getY
        bbx=pntList.get(idx+1).getX
        bby=pntList.get(idx+1).getY
        AC=((bbx-aax)*(ccx-aax))+((bby-aay)*(ccy-aay))
’chkingDotProductOf A->C->
        BC=((aax-bbx)*(ccx-bbx))+((aay-bby)*(ccy-bby))
’chkingDotProductOF B->C->
        LAC=((ccx-aax)*(ccx-aax)+((ccy-aay)*(ccy-aay)))
’chking Dist between A and C 8/1
        if (LAC < 5) then
          pFound=True
          distList.add(LAC.clone)
          nPntList.add(pntList.get(idx).clone)
          cLenList.add(cLength.clone)
        end
        ABL=(((bbx-aax)^2)+((bby-aay)^2))
        tLength=tLength+(ABL.sqrt)
        if((AC<0) or (BC<0))then  ’segment AB doesn’t contain
point C
          if(oldAC=nil)then
            oldAC=AC
          else
            if((oldAC*AC)<0)then  ’Angle changes from <90 to
>90, the end point contains thePntV
              newX=aax
              newY=aay
              newPnt=point.make(newX,newY)
              ACLength=(((ccx-aax)^2)+((ccy-aay)^2)).sqrt
              if(not (ACLength.isnull))then
                distList.add(ACLength.clone)
                nPntList.add(newPnt.clone)
                cLenList.add(cLength.clone)
                pFound=true
              end
            else
              oldAC=AC
            end
          end  ’(OldAC=nil)
          cLength=cLength+(ABL.sqrt)
        else  ’Segment AB contains point C
          ACLength=(((ccx-aax)^2)+((ccy-aay)^2)).sqrt
          newX=aax+((bbx-aax)*AC/ABL)
          newY=aay+((bby-aay)*AC/ABL)
          cLength=cLength+(AC/(ABL.sqrt))   ’AC=A dot C
          cosA=AC/(ABL*ACLength)
          sinA=(1-(cosA^2)).sqrt
          dist=ACLength*sinA
          if(not (dist.isnull))then  ’Zye 7/8/97
            distList.add(dist.clone)
            newPnt=point.make(newX,newY)
            nPntList.add(newPnt.clone)
            cLenList.add(cLength.clone)
            pFound=true
          end
        end
      end ’end for each idx
    end ’endif(PntList.count<=2)

    if(pFound.Not)then
      newpnt=nil
    else
      if(pntList.Count>2)then
        nMatch=nPntList.count
        ndx=0
        minDist=distList.get(0)
```

```
        newPnt=nPntList.get(0)
        cLength=clenList.get(0)
        if(nMatch>1)then
          for each i in 1..(nMatch-1)
            tmpDist=distList.get(i)
            if(tmpDist<minDist)then
              minDist=tmpDist.clone
              cLength=cLenList.get(i).clone
              newPnt=nPntList.get(i).clone
            end
          end
        end
      end
    end 'if(notFound)

    if(newPnt=nil)then
      problemList.add(Inpnt)
    end
  end

  pcnt=theShpV.pointposition(newPnt)
  newPntRec=newFtab.addrecord
  newFtab.setvalue(newPntFld, newPntRec, newPnt)
  newFtab.setvalue(newTypeFld, newPntRec, inPntType)
  newFtab.setvalue(arcIdFld, newPntRec, theArcV)
  newFtab.setvalue(pcntFld, newPntRec, pcnt)
  idValue=pntFtab.returnvalue(idFld, thePntRec)
  newFtab.setvalue(newIdFld,newPntRec,idValue)
  av.setstatus(item/total*100)
  recs.empty
 end 'if ((recs.isempty).not)
end  'end of the main (for each item..) loop
```

```
pntThm.selectbyshapes(problemlist,#VTAB_SELTYPE_XOR)

av.setstatus(100)
pntFtab.seteditable(false)
newFtab.seteditable(false)
exit
```

' **Script: wrap.snapcp_tool, wrap26.ave**

```
'
' Description: Snaps control point to arc selected
'    from line theme
'
' History: Combination of wrap.addcp_tool and
wrap.snapcp_menu.
'    Brad Hudgens 9/7/99

theView=av.getactivedoc
Thedir=av.getproject.getworkdir

theActThemes=list.make
theActThemes=theView.getActivethemes
if ((theActThemes.count)<>1) then
  msgbox.error("The line theme should be the only theme
active","WRAP Parameters")
  exit
end
lineThm=theActThemes.get(0)
if (lineThm=nil) then
  msgbox.error("Error opening line theme","WRAP
Parameters")
```

```
  exit
end
rTheme=lineThm
rFtab=rTheme.getftab
rShape=rFtab.findfield("Shape")
rArcId=rFtab.findfield("ArcID")

pntThmName=_snapCpThm+".shp"
if (_snapCpThm=nil) then
  msgbox.info("Set the control point theme names in the WRAP Tools menu","WRAP Parameters")
  exit
end
pntFileName=FN.Merge(Thedir.AsString,_snapCpThm+".shp")

'identify the tool that called the script
theTool=av.getactivegui.gettoolbar.getactive.gettag

'get the control point
inPnt=theView.getdisplay.returnuserpoint

'input type and id number of control point
options={ "Diversion point","Return flow","Other secondary","Stream gage","Other primary"}
choise=msgbox.choiceasstring(options,"Choose the type of control point:","WRAP Parameters")
if (choise=nil)then
  msgbox.error("No Selection","WRAP Parameters")
end
id_string=msgbox.input("Enter the ID number:","WRAP Parameters","0")
if (id_string.isnumber) then
  id_number=id_string.asnumber
else
  msgbox.error("ID must be an integer","WRAP Parameters")
  exit
end

'If this is the first point, make the FTab
if(theView.findtheme(pntThmName)=nil) then

  pntFtab=ftab.makenew(pntFileName,point)
  pntTheme=ftheme.make(pntFtab)

  pntFields=list.make
  pntFields.add(field.make("ID",#Field_Long,12,1))
  pntFields.add(field.make("Type",#Field_VChar,20,0))
  pntfields.add(field.make("ArcID",#Field_Long,12,0))
  pntfields.add(field.make("distance",#Field_Long,4,0))
  pntFieldsC=pntFields.deepclone

  pntFtab.addFields(pntFieldsC)
  theView.addtheme(pntTheme)

  if(pntFtab.canedit) then
    pntFtab.seteditable(true)
  else
    msgbox.error("Can't edit the output theme.","WRAP Parameters")
    exit
  end
  pntTheme.setvisible(true)

'If this is not the first point, get the FTab
else
```

```
'Check Ftab for duplicate id numbers
  pntTheme=theView.findtheme(pntThmName)
  table_pnt=pntTheme.getftab
  field_id=table_pnt.findfield("ID")
  for each rec in table_pnt
    if (table_pnt.returnvalue(field_id,rec)=id_number)then
      msgbox.error("ID number duplicated","WRAP Parameters")
      exit
    end
  end

  pntFtab=pntTheme.getftab
  if(pntFtab.canedit) then
    pntFtab.seteditable(true)
  else
    msgbox.error("Can't edit point theme.","WRAP Parameters")
    exit
  end
end

pntFld=pntFtab.findfield("Shape")
idFld=pntFtab.findfield("ID")
typeFld=pntFtab.findfield("Type")
arcIdFld=pntFtab.findfield("ArcID")
pcntFld=pntFtab.findfield("distance")

thePntV=inPnt

count=0
for each rec in rFtab.getselection
  count=count+1
end

if (count<1) then
  msgbox.error("No arcs selected in line theme","WRAP
Parameters")
  exit
end

if (count>1) then
  msgbox.error("More than one arc selected in line
theme","WRAP Parameters")
  exit
end

for each rec in rFtab.getselection
  theShpV=rFtab.returnvalue(rShape, rec)
  theArcV=rFtab.returnvalue(rArcId, rec)
end

pntList=theShpV.asmultipoint.aslist
ccx=thePntV.getX
ccy=thePntV.getY
cLength=0.0
distList=list.make  'Dists between each potential snap point and
original point.
nPntList=list.make  'Potential snap-to points.
cLenList=list.make  'Dists between from node to each potential
snap-to points.
if(pntList.count=2)then
  aax=pntList.get(0).getX
  aay=pntList.get(0).getY
  bbx=pntList.get(1).getX
  bby=pntList.get(1).getY
  tLength=(((bbx-aax)^2)+((bby-aay)^2))^(0.5)
  AC=((bbx-aax)*(ccx-aax))+((bby-aay)*(ccy-aay))
```

```
  cLength=AC/tLength  'A.C=A.abs*C.abs*Cos(AC),
Clength=C.abs*Cos(AC), A.abs=TLength
  newX=aax+((bbx-aax)*(cLength/tLength))
  newY=aay+((bby-aay)*(cLength/tLength))
  newPnt=point.make(newX,newY)
  pFound=true
else
  pcnt=pntList.count-2
  pFound=false
  'Start computation loop
   oldAC=nil
   tLength=0.0
   for each idx in 0..pcnt
     aax=pntList.get(idx).getX
     aay=pntList.get(idx).getY
     bbx=pntList.get(idx+1).getX
     bby=pntList.get(idx+1).getY
     AC=((bbx-aax)*(ccx-aax))+((bby-aay)*(ccy-aay))
'chkingDotProductOf A->C->
     BC=((aax-bbx)*(ccx-bbx))+((aay-bby)*(ccy-bby))
'chkingDotProductOF B->C->
     LAC=((ccx-aax)*(ccx-aax)+((ccy-aay)*(ccy-aay))) 'chking
Dist between A and C 8/1
     if (LAC < 5) then
       pFound=true
       distList.add(LAC.clone)
       nPntList.add(pntList.get(idx).clone)
       cLenList.add(cLength.clone)
     end                                        '8/1
     ABL=(((bbx-aax)^2)+((bby-aay)^2))
     tLength=tLength+(ABL.Sqrt)
     if((AC<0) or (BC<0))then  'segment AB doesn'tContain
Point C
       if(oldAC=nil)then
         oldAC=AC
       else
         if((oldAC*AC)<0)then  'Angle changes from <90 to >90,
the end point contains thePntV
           newX=aax
           newY=aay
           newPnt=point.make(newX,newY)
           ACLength=(((ccx-aax)^2)+((ccy-aay)^2)).sqrt
           if(not (ACLength.isnull))then
             distList.add(ACLength.clone)
             nPntList.add(newPnt.clone)
             cLenList.add(cLength.clone)
             pFound=true
           end
         else
           oldAC=AC
         end
       end
         cLength=cLength+(ABL.sqrt)
     else  'Segment AB contains point C
       ACLength=(((ccx-aax)^2)+((ccy-aay)^2)).sqrt
       newX=aax+((bbx-aax)*AC/ABL)
       newY=aay+((bby-aay)*AC/ABL)
       cLength=cLength+(AC/(ABL.sqrt))   'AC=A dot C
       cosA=AC/(ABL*ACLength)
       sinA=(1-(cosA^2)).sqrt
       dist=ACLength*sinA
       if(not (dist.isnull))then  'Zye 7/8/97
         distList.add(dist.clone)
         newPnt=point.make(newX,newY)
         nPntList.add(newPnt.clone)
         cLenList.add(cLength.clone)
```

```
        pFound=true
      end
    end
  end ’endfor each idx
 end ’endif(PntList.count<=2)

if(pFound.not)then
  newPnt=nil
else
  if(pntList.count>2)then
    nMatch=nPntList.count
    ndx=0
    minDist=distList.get(0)
    newPnt=nPntList.get(0)
    cLength=cLenList.get(0)
    if(nMatch>1)then
      for each i in 1..(nMatch-1)
        tmpDist=distList.get(i)
        if(tmpDist<minDist)then
          minDist=tmpDist.clone
          cLength=cLenList.get(i).clone
          newPnt=nPntList.get(i).clone
        end
      end
    end
  end
end ’if(notFound)

thePcnt=theShpV.pointposition(newPnt)

newPntRec=pntFtab.addrecord
pntFtab.setvalue(pntFld, newPntRec, newPnt)
pntFtab.setvalue(typeFld, newPntRec, choise)
pntFtab.setvalue(arcIdFld, newPntRec, theArcV)
pntFtab.setvalue(idFld, newPntRec, id_string)
pntFtab.setvalue(pcntFld, newPntRec, thePcnt)

av.setstatus(100)
’Stop editing and clear tool
pntFTab.seteditable(false)
theTool=nil
```

’ Script: wrap.stripfields, wrap27.ave

```
’
’ Description: Deletes all but selected fields from a selected
theme.
’ Used specifically to remove RF3 attribute fields.
’
’ History: Original by Brad Hudgens, 9/24/99

fieldList={}
keepList={}
dropList={}

theView = av.getactivedoc
av.showstopbutton

’get themes
theThemes = theView.getthemes
if (theThemes.count = 0) then
   msgbox.error("No themes found", "WRAP Parameters")
   exit
```

```
end

theFthemes = list.make
for each theTheme in theThemes
  if (theTheme.getclass.getclassname = "ftheme") then
    theFthemes.add(theTheme)
  end
end
if (theFthemes.count = 0) then
  msgbox.error("No coverage themes found","WRAP
Parameters")
  exit
end

'select coverage to strip fields
theTheme = msgbox.choice(theFthemes, "Select the Shapefile
to Strip Fields","WRAP Parameters")
if (theTheme = nil) then
  exit
end

theFtab = theTheme.getftab
if (theFtab = nil) then
    msgbox.error("Can't open control point coverage","WRAP
Parameters")
    exit
end

fieldList=theFtab.getFields

keepField=theFtab.findField("Shape")
keepList.add(keepField)
while (keepField<>nil)
  keepField=msgbox.choiceasstring(fieldList, "Select the Fields
to Keep.  Click Cancel to end", "WRAP Parameters")
  keepList.add(keepField)
end

dropList=fieldList.clone

for each item1 in fieldList
  for each item2 in keepList
    if (item1=item2) then
      dropList.removeobj(item1)
    end
  end
end

theFTab.seteditable(true)
theFtab.removeFields(dropList)
theFtab.seteditable(false)
```

```
'Script: wrap.strmsort, wrap28.ave
'
'Description: Determines connectivity among arcs in stream
network.  Arbitrary ID numbers
'are assigned to each arc and the downstream arc determined
'
'History: Created by Richard Gu  11/26/98

sMsg="WRAP Parameters"
```

```
TheView=av.getactivedoc
lineThmList=theView.getthemes

'get themes
theThemes = theview.getthemes
if (theThemes.count = 0) then
    msgbox.error("No themes found", "WRAP Parameters")
    exit
end

theFthemes = list.make
for each theTheme in theThemes
  if (theTheme.getclass.getclassname = "ftheme") then
    theFthemes.add(theTheme)
  end
end
if (theFthemes.count = 0) then
  msgbox.error("No coverage themes found","WRAP
Parameters")
  exit
end

'select stream network theme
LineThm=Msgbox.ChoiceAsString(theFthemes, "Select
network to build arc connectivity", sMsg)
if (LineThm=nil) then
  Exit
end

theFtab=lineThm.getFtab
theFtab.seteditable(true)
nLines=theFtab.getnumrecords
theFtab.seteditable(true)

if (theFtab.findfield("ArcID")=nil) then
  segNumFld=field.make("ArcID", #FIELD_LONG, 4,0)
  theFtab.addfields({segNumFld})
end

segNumFld=theFtab.findfield("ArcID")

i=0
for each lrec in theFtab
  i=i+1
  theFtab.setvalue(segNumFld,lrec,i)
end

nextSegNumFld=field.make("DSArcID", #FIELD_LONG, 4,0)
if(theFtab.findfield("DSArcID")=nil)then
  theFtab.addfields({nextSegNumFld})
end
lineShapef=theFtab.findfield("Shape")
nextSegf=theFtab.findfield("DSArcID")

'search for next downstream segment
for each lrec in theFtab
  chkDirFlag=0
  lineShape=theFtab.returnvalue(lineShapef,lrec)
  fstList=lineShape.asmultipoint.aslist
  searchPntA=fstList.get(fstList.count-1)
  searchPntB=fstList.get(0)
  lnRec=lrec
  searchShape=lineShape
  segValue=theFtab.returnvalue(segNumFld,lrec)
```

```
for each lrec in theFtab
    lineShape=theFtab.returnvalue(lineShapef,lrec)
    lineNum=theFtab.returnvalue(segNumFld, lrec)

if(searchPntA.intersects(lineShape)and(searchShape.iscontained
in(lineShape).not))then
      sndList=lineShape.asmultipoint.aslist
      compPntA=sndList.get(0)

if(compPntA.intersects(searchShape)and(searchPntB.iscontaine
din(lineShape).not))then
        chkDirFlag=chkDirFlag+1
'        theFtab.setvalue(nextSegf,lrec,segValue)
        theFtab.setvalue(nextSegf,lnRec,lineNum)
      end
    end
  end
  if(chkDirFlag>1)then
    msgbox.info("wrong direction","")
    break
  end
  bstop=av.setStatus(lrec/nLines*100).not
end

theFtab.seteditable(false)
av.setstatus(100)

'--- Since there are changes in methodologies, there is no need to
do the following job.
'--- It is a pity that I have to put the exit here that to stop the
execution. However,
'--- I reserve the code in case someday, the bueaty can be
realized.
```

```
EXIT


if(ChkDirFlag>1)then
'do the reverse search
for each lrec in TheFtab
  LineShape=TheFtab.Returnvalue(LineShapef,lrec)
  FstList=LineShape.AsMultiPoint.AsList
  SearchPntB=FstList.get(FstList.Count-1)
  SearchPntA=FstList.get(0)
  LnRec=lrec
  SearchShape=LineShape
  SegValue=TheFtab.ReturnValue(SegNumFld,lrec)

  for each lrec in TheFtab
    LineShape=TheFtab.ReturnValue(LineShapef,lrec)
'check to make sure not to compare with itself

if(SearchPntA.Intersects(LineShape)and(SearchShape.IsContain
edIn(LineShape).not))then
      SndList=LineShape.AsMultiPoint.AsList
      CompPntA=SndList.Get(SndList.Count-1)
' this part take care the parallel

if(CompPntA.Intersects(SearchShape)and(SearchPntB.Intersect
s(LineShape).not))then
        TheFtab.SetValue(NextSegf,lrec,SegValue)
      end
    end
  end
  bstop=av.setStatus(lrec/nLines*100).not    '***check the
progress
```

```
end
end  'end if(ChkDirFlag>1)

if (bStop) then  '***the procedure is complete
    TheFtab.SetEditable(false)
end
```

'Script: wrap.unproject, wrap29.ave

```
'
'Description: Adds lat and long coordinates to a point coverage
ftab
'
'History: Created by Brad Hudgens 10/20/99

theView=av.getactivedoc
theProject=av.getproject
theDir=theProject.getworkdir.asstring

'get themes
theThemes = theView.getthemes
if (theThemes.count = 0) then
    msgbox.error("No themes found", "WRAP Parameters")
    exit
end

theFthemes = list.make
for each theTheme in theThemes
  if (theTheme.getclass.getclassname = "ftheme") then
    theFthemes.add(theTheme)
  end
end
if (theFthemes.count = 0) then
  msgbox.error("No feature themes found","WRAP
Parameters")
  exit
end

'select the point coverage
ptTheme = msgbox.choice(theFthemes, "Select the Point
Theme","WRAP Parameters")
if (ptTheme = nil) then
  exit
end
theFtab=ptTheme.getftab

'check for definition of map units
sourceUnits = theView.getdisplay.getunits

if (sourceUnits = #UNITS_LINEAR_UNKNOWN) then
  MsgBox.Error("View units must be set before projecting.",
              "WRAP Parameters")
  exit
end

'user defines current projection
inputPrj = ProjectionDialog.show(theView,sourceUnits)
  if (inputPrj.IsNull) then
    return nil
  end

'add sequentially indexed key field to point ftab
theFtab.seteditable(true)
newFld1=list.make
```

```
newFld1.add(field.make("keyfield",#field_long,10,0))
theFtab.addfields(newFld1)
keyFld=theFtab.findfield("keyfield")
keyNum=1
for each rec1 in theFtab
  theFtab.setvalue(keyFld, rec1, keyNum)
  keyNum=keyNum+1
end

'export ftab as unprojected -- geo,dd
exportString=theDir+"cpidkey"
exportFtab=theFtab.exportunprojected(exportString.asfilename,
inputPrj, false)
ddSrcName=SrcName.make(exportString+".shp")
ddFtab=ftab.make(ddSrcName)

'add x and y coordinates
ddftab.seteditable(true)
newFld2=list.make
newFld2.add(field.make("x",#field_decimal,11,6))
newFld2.add(field.make("y",#field_decimal,11,6))
ddFtab.addfields(newFld2)
xFld=ddFtab.findfield("x")
yFld=ddFtab.findfield("y")
ddShpFld=ddFtab.findfield("Shape")
for each rec2 in ddFtab
  ddPt=ddFtab.returnvalue(ddShpFld, rec2)
  theX=ddPt.getx
  theY=ddPt.gety
  ddFtab.setvalue(xFld, rec2, theX)
  ddFtab.setvalue(yFld, rec2, theY)
end
ddFtab.seteditable(false)

'add fields to original ftab
newFld3=list.make
newFld3.add(field.make("Long",#field_decimal,11,6))
newFld3.add(field.make("Lat",#field_decimal,11,6))
theFtab.addfields(newFld3)

'join ddFtab to theFtab and copy over x and y fields
ddKeyFld=ddFtab.findfield("keyfield")
theFtab.join(keyFld, ddFtab, ddKeyFld)
theXFld=theFtab.findfield("x")
theYFld=theFtab.findfield("y")
longFld=theFtab.findfield("Long")
latFld=theFtab.findfield("Lat")
for each rec3 in theFtab
  theX3=theFtab.returnvalue(theXFld, rec3)
  theFtab.setvalue(longFld, rec3, theX3)
  theY3=theFtab.returnvalue(theYFld, rec3)
  theFtab.setvalue(latFld, rec3, theY3)
end

theFTab.unjoinall
theFtab.removefields({keyFld})
theFtab.seteditable(false)

exit
```

```
'Script: wrap.watersheds, wrap30.ave
'
'Description: Delineates watersheds for each control point.
'Outputs polygon theme.
'
'History: Modified by Brad Hudgens 9/24/99 from CRWR
Prepro

theView=av.getactivedoc
theProject=av.getproject
theDir=theProject.getworkdir.asstring

'get themes
theThemes = theView.getthemes
if (theThemes.count = 0) then
   msgbox.error("No themes found", "WRAP Parameters")
   exit
end

theFthemes = list.make
for each theTheme in theThemes
  if (theTheme.getclass.getclassname = "ftheme") then
    theFthemes.add(theTheme)
  end
end
if (theFthemes.count = 0) then
  msgbox.error("No feature themes found","WRAP
Parameters")
  exit
end

theGthemes = list.make
for each theTheme in theThemes
  if(theTheme.getclass.getclassname = "gtheme") then
    theGthemes.add(theTheme)
  end
end
if (theGthemes.count = 0) then
  msgbox.error("No grid themes found","WRAP Parameters")
  exit
end

'select flow direction grid
fdrTheme = msgbox.choice(theGthemes, "Select the Flow
Direction Grid","WRAP Parameters")
if (fdrTheme = nil) then
  exit
end

'select the control point coverage
cpTheme = msgbox.choice(theFthemes, "Select the Control
Point Theme","WRAP Parameters")
if (cpTheme = nil) then
  exit
end

fdrGrid=fdrTheme.getgrid

'add sequentially indexed key field to cp ftab
cpFtab=cpTheme.getftab
cpFtab.seteditable(true)
newField=list.make
newField.add(field.make("keyfield",#field_long,10,0))
cpFtab.addfields(newField)
keyFld=cpFtab.findfield("keyfield")
keyNum=1
```

```
for each rec1 in cpFtab
  cpFtab.setValue(keyFld, rec1, keyNum)
  keyNum=keyNum+1
end
cpFtab.seteditable(false)

thePrj=prj.makenull
theGridSize=nil

theFlds=cpFtab.getfields
idFld=msgbox.choice(theFlds, "Select the actual control point
identifier field","WRAP Parameters")
idFldStr=idFld.getname

'make outlet grid with key field
cpGrid=cpFtab.asgrid(theprj, keyFld, theGridsize)

waterGrd=fdrGrid.watershed(cpGrid)    'Construct
WatershedGrd
outTheme = gtheme.make(waterGrd)
outTheme.setname("ShedGrid")

inGrd=outTheme.getgrid

'vectorize watershed grid
aFileName="Watrshed.shp".asfilename
resultFtab=inGrd.aspolygonftab(aFileName,false,prj.makenull)

'field editing
resultFtab.seteditable(true)
killFld=resultFtab.findfield("ID")
resultFtab.removefields({killFld})
newFields=list.make
newFields.add(field.make("CP",#field_long,12,0))
newFields.add(field.make("IncArea(sq.mi.)",#field_float,20,4))
resultFtab.addfields(newFields)

'join watershed ftab to original cp ftab by key field
gcField=resultFtab.findfield("gridcode")
resultFtab.join(gcField, cpFtab, keyFld)

shpField=resultFtab.findfield("Shape")
cpIdFld=resultFtab.findfield(idFldStr)
newcpField=resultFtab.findfield("CP")
areaField=resultFtab.findfield("IncArea(sq.mi.)")

'copy over original control point identifiers and add inc area
for each rec in resultFtab
  theID=resultFtab.returnvalue(cpIdFld, rec)
  resultFtab.setvalue(newcpField, rec, theID)
  theShape=resultFtab.returnvalue(shpField, rec)
  theArea = theShape.returnarea
  sqmi = theArea*0.000000386102
  resultFtab.setvalue(areaField, rec, sqmi)
end

resultFtab.unjoinall
resultFtab.removefields({gcField})
resultFtab.seteditable(false)

theFthm=ftheme.make(resultFtab)
theView.addtheme(theFthm)
exit
```

AML : dem30m

Description : Builds integer DEM for basin from original NED grids

History : Original 4/25/99 by Brad Hudgens

```
grid
cm9433 = 100 * dem9433
kill dem9433 all
cm9434 = 100 * dem9434
kill dem9434 all
cm9533 = 100 * dem9533
kill dem9533 all
cm9534 = 100 * dem9534
kill dem9534 all
cm9633 = 100 * dem9633
kill dem9633 all
cm9634 = 100 * dem9634
kill dem9634 all
cm9733 = 100 * dem9733
kill dem9733 all
cm9734 = 100 * dem9734
kill dem9734 all
int9433 = int(cm9433)
kill cm9433 all
int9434 = int(cm9434)
kill cm9434 all
int9533 = int(cm9533)
kill cm9533 all
int9534 = int(cm9534)
kill cm9534 all
int9633 = int(cm9633)
kill cm9633 all
int9634 = int(cm9634)
kill cm9634 all
int9733 = int(cm9733)
kill cm9733 all
int9734 = int(cm9734)
kill cm9734 all
demgeo =
merge(int9433,int9434,int9533,int9534,int9633,int9634,int9733
,int9734)
kill int9433 all
kill int9434 all
kill int9533 all
kill int9534 all
kill int9633 all
kill int9634 all
kill int9733 all
kill int9734 all
quit
project grid demgeo demalb
output
projection Albers
datum NAD83
spheroid GRS1980
units meters
parameters
27 25 0
34 55 0
-100 0 0
31 10 0
1000000
```

1000000
end
kill demgeo all

AML : reprodrg

Description : project DRG files

History : Original by Brad Hudgens 12/01/98

```
imagegrid o33096b1 gridb1z14 color1
delete o33096b1
project grid gridb1z14 gridb1z15 z14toz15.txt
kill gridb1z14 all
gridimage gridb1z15 color1 o33096b1 tiff compression
kill gridb1z15 all
imagegrid o33096c1 gridc1z14 color1
delete o33096c1
project grid gridc1z14 gridc1z15 z14toz15.txt
kill gridc1z14 all
gridimage gridc1z15 color1 o33096c1 tiff compression
kill gridc1z15 all
imagegrid o33096c2 gridc2z14 color1
delete o33096c2
project grid gridc2z14 gridc2z15 z14toz15.txt
kill gridc2z14 all
gridimage gridc2z15 color1 o33096c2 tiff compression
kill gridc2z15 all
imagegrid o33096d1 gridd1z14 color1
delete o33096d1
project grid gridd1z14 gridd1z15 z14toz15.txt
kill gridd1z14 all
gridimage gridd1z15 color1 o33096d1 tiff compression
kill gridd1z15 all
imagegrid o33096d2 gridd2z14 color1
delete o33096d2
project grid gridd2z14 gridd2z15 z14toz15.txt
kill gridd2z14 all
gridimage gridd2z15 color1 o33096d2 tiff compression
kill gridd2z15 all
imagegrid o33096e1 gride1z14 color1
delete o33096e1
project grid gride1z14 gride1z15 z14toz15.txt
kill gride1z14 all
gridimage gride1z15 color1 o33096e1 tiff compression
kill gride1z15 all
```

AML : albtodem

Description : Projects from TSMS Albers to USGS DEM

```
input
projection Albers
spheroid GRS1980
datum nar_c
units meters
```

```
parameters
27 25 0
34 55 0
-100 0 0
31 10 0
1000000
1000000
output
projection geographic
spheroid WGS72
datum WGS72
units ds
parameters
end
```


AML : albtoutm

Description : Projects from TSMS Albers to UTM

```
input
projection Albers
spheroid GRS1980
datum NAD83
units meters
parameters
27 25 0
34 55 0
-100 0 0
31 10 0
1000000
1000000
output
projection utm
zone 15
spheroid clarke1866
datum NAD27
units meters
parameters
end
```

AML : bastoutm

Description : Projects from EPA BASINS RF3 data projection to UTM

```
input
projection geographic
datum NAD83
spheroid GRS1980
units dd
parameters
output
projection utm
zone 15
datum NAD27
spheroid clarke1866
units meters
parameters
end
```

AML : demtoalb

Description : Projects USGS DEM to TSMS Albers

```
input
projection geographic
spheroid WGS72
datum WGS72
units ds
parameters
output
projection Albers
spheroid GRS1980
datum nar_c
units meters
parameters
27 25 0
34 55 0
-100 0 0
31 10 0
1000000
1000000
end
```

AML : gagtoalb

Description : Projects USGS gage data to TSMS Albers

```
input
projection geographic
spheroid clarke1866
datum NAD27
units dd
parameters
output
projection Albers
spheroid GRS1980
datum NAD83
units meters
parameters
27 25 0
34 55 0
-100 0 0
31 10 0
1000000
1000000
end
```

AML : gagtoutm

Description : Projects USGS gage data to UTM

```
input
projection geographic
spheroid clarke1866
datum NAD27
units dd
```

```
parameters
output
projection utm
zone 15
spheroid clarke1866
datum NAD27
units meters
parameters
end
```

AML : utmtoalb

Description : Projects UTM to TSMS Albers

```
input
projection utm
zone 15
spheroid clarke1866
datum NAD27
units meters
parameters
output
projection Albers
spheroid GRS1980
datum NAD83
units meters
parameters
27 25 0
34 55 0
-100 0 0
31 10 0
1000000
1000000
end
```

AML : z14toz15

Description : Projects UTM zone 14 to UTM zone 15

```
input
projection utm
zone 14
datum NAD27
spheroid clarke1866
units meters
parameters
output
projection utm
zone 15
datum NAD27
spheroid clarke1866
units meters
parameters
end
```

References

Bauer, B., 1980. *Drainage Density : an Integrative Measure of the Dynamics and Quality of Watersheds*. Cited in : *Morphometry of Drainage Basins*, by I. Zavoianu. Elsevier Science Publishers, 1985.

Boghici, E., 1999. Personal Communication. Texas Natural Resource Information System.

Bridge, J.S., 1993. *The Interaction Between Channel Geometry, Water Flow, Sediment Transport, and Deposition in Braided Rivers*. Published in : *Braided Rivers*, edited by J.L. Best and C.S. Bristow. The Geological Society, 1993.

Bondelid, T.R., Jackson, T.J., and McCuen, R.H., 1982. *Estimating Runoff Curve Numbers Using Remote Sensing Data*. Published in : *Applied Modeling in Catchment Hydrology*, edited by V.P. Singh. Water Resources Publications, 1982.

Clark, M.J., 1993. *Data Constraints on GIS Application Development for Water Resources Management*. Published in : *Application of Geographic Information Systems in Hydrology and Water Resources Management*, edited by K. Kovar and H.P. Nachtnabel. International Association of Hydrological Sciences Publication No. 211, 1993.

CRWR, 1999. *Draft Procedure for the River Basin Database Development of the Water Availability Modeling Project*. Center for Research in Water Resources, 1999.

Daly, C., 1998. *Central United States Average Monthly or Annual Precipitation, 1961-1990*; Metadata. Internet Site : http://www.ocs.orst.edu/pub/maps/Precipitation/Total/Regional/Central/cent_rast_meta.html

Dartigenauve, C., 1998. *Water Quality Master Planning for Austin*. CRWR Online Report 97-6. Internet Site : http://www.crwr.utexas.edu/gis/gishyd98/library/dartig/rpt97_6.html

Dobkins, B.E., 1959. *The Spanish Element in Texas Water Law*. University of Texas Press.

EPA, 1994. *The U.S. EPA Reach File Version 3.0 Alpha Release (RF3-Alpha) Technical Reference*. Internet Site : http://www.epa.gov/OWOW/NPS/rf/techref.html

ESRI, 1998. *NAD to WGS*. ARC Version 7.2.1 On-line Help Topic.

Grayson, R.B., Bloschl, G., Barling, R.D., Moore, I.D., 1993. *Process, Scale, and Constraints to Hydrological Modelling in GIS*. Published in : *Application of Geographic Information Systems in Hydrology and Water Resources Management*, edited by K. Kovar and H.P. Nachtnabel. International Association of Hydrological Sciences Publication No. 211, 1993.

Horton, R.E., 1945. *Erosional Development of Streams and their Drainage Basins: Hydrophysical Approach to Quantitative Morphology*. Cited in : *Channel Network Hydrology*, edited by K. Beven and M.J. Kirkby. John Wiley and Sons, 1993.

Jonsdottir, J., 1999. *Digital Delineation of Watershed Drainage Areas.* Internet Site : http://www.ce.utexas.edu/stu/jonsdoj/termpaper/termpaper.html

Kirkby, M.J., 1993. *Network Hydrology and Geomorphology*. Published in : *Channel Network Hydrology*, edited by K. Beven and M.J. Kirkby. John Wiley and Sons, 1993.

Lane, 1957. Published in : *Braided Rivers*, edited by J.L. Best and C.S. Bristow. The Geological Society, 1993.

Maidment, D.R., 1991. *GIS and Hydrological Modeling*. Published in : *Proceedings of First International Symposium/Workshop on GIS and Environmental Modeling*, edited by M.F. Goodchild, B.O. Parks, and L.T. Steyaert. Oxford University Press, 1991.

Maidment, D.R., 1998. *Module 4 : Geodesy and Map Projections*. Internet Site : http://www.engr.utexas.edu/giswr/secure/Module4/mod4html/module4.htm

Olivera, F., 1998. *Spatial Hydrology of the Urubamba River System in Peru Using Geographic Information Systems (GIS)*. Internet Site : http://www.ce.utexas.edu/prof/olivera/peru/peru.htm

Quenzer, A.M., 1998. *A GIS Assessment of the Total Loads and Water Quality in the Corpus Christi Bay System*. CRWR Online Report 98-1. Internet Site : http://www.ce.utexas.edu/prof/maidment/grad/quenzer/home.html

R.J. Brandes Co., 1999. *Water Availability Modeling for the Sulphur Basin*; Draft. R.J. Brandes Company.

Saunders, W., 1996. *A GIS Assessment of Nonpoint Source Pollution in the San Antonio-Nueces Coastal Basin*. Internet Site : http://www.ce.utexas.edu/prof/maidment/GISHYDRO/saunders/report.htm

Skillern, F.F., 1988. *Texas Water Law*. Sterling Press Inc.

TNRCC, 1998. *Digital Elevation Modeling for the WAM and other TNRCC OWRM Projects*; Draft. Texas Natural Resource Conservation Commission.

TNRCC, 1999. *WAM : Water Availability Modeling, an Overview*. Internet Site : http://www.tnrcc.state.tx.us/admin/topdoc/gi/245/

Town, M., 1999. Personal Communication. Texas Natural Resources Conservation Commission.

TWDB, 1984. *Water for Texas*. Texas Water Development Board.

USDA, 1999. *NRCS Data Resources*. Internet site : http://www.ftw.nrcs.usda.gov/soils_data.html

Wurbs, R.A., Sisson, E.D., 1998. *Comparative Evaluation of Watershed Characteristics and Methods for Distributing Naturalized Streamflows from Gaged to Ungaged Sites*. Texas Water Resources Institute. Texas A&M University.

Zavioanu, I., 1985. *Morphometry of Drainage Basins*. Elsevier Science Publishing.

Vita

Bradley Taylor Hudgens was born in Long Beach, California on December 29, 1970, the son of Alva Vernon Hudgens and Beverly Faythe Hudgens. After completing his work at Jenks High School, Jenks, Oklahoma, he entered the University of Pennsylvania in Philadelphia, Pennsylvania. He received the degree of Bachelor of Science in Engineering from the University of Pennsylvania in May, 1993. Upon graduation he was commissioned a Lieutenant in the United States Army and served as a Military Intelligence officer for four years. In January, 1998, he entered the Graduate School at the University of Texas.

Permanent address: 8243 South Sandusky
Tulsa, Oklahoma 74137

This thesis was typed by the author.